THE ATMOSPHERE

INSTITUTE OF EDUCATION FOR WOMEN
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by E. S. BROWN

HOW THE EARTH IS MADE
by PETER HOOD

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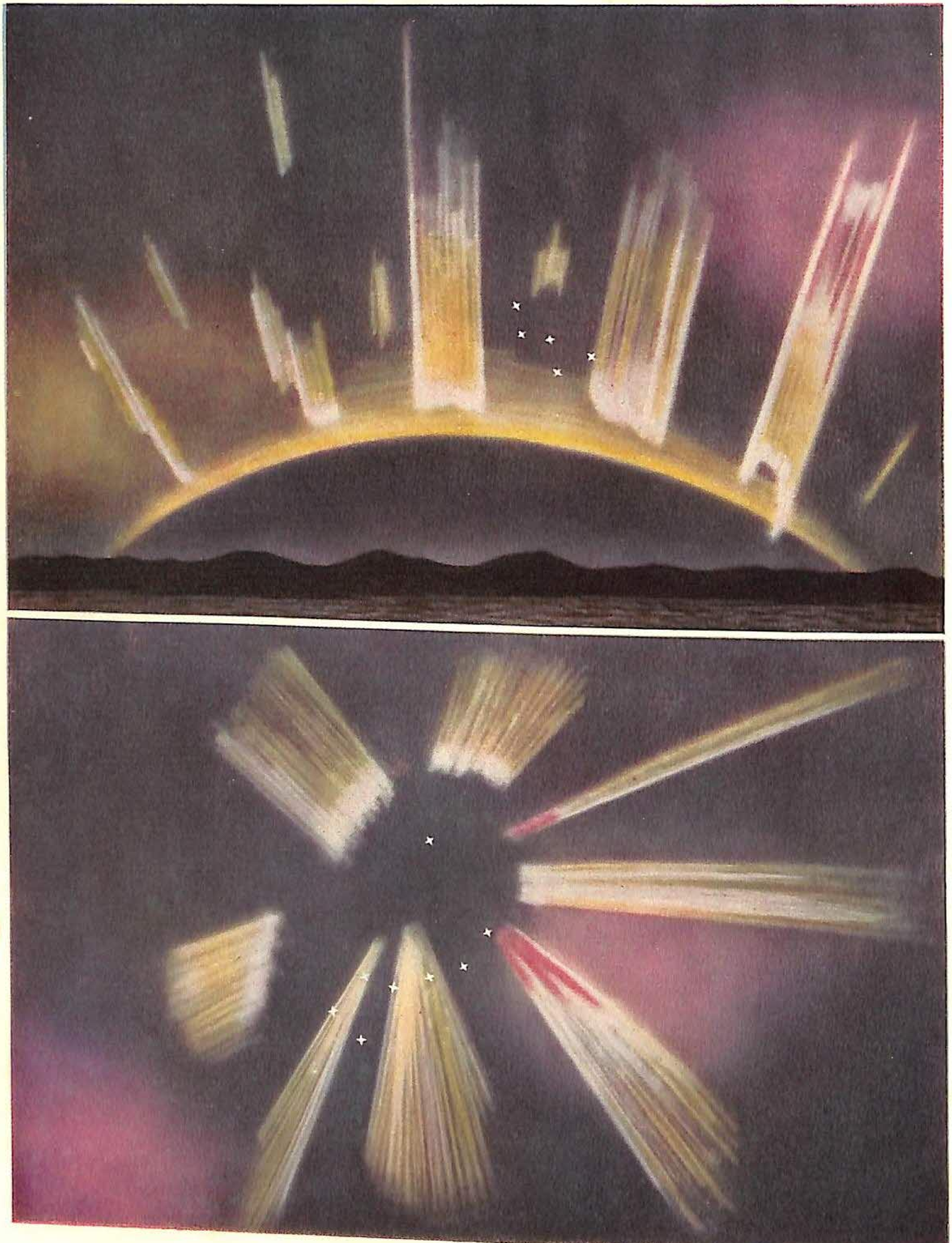

Drawn from observations supplied by W. B. Housman, F.R.A.S.

THE AURORA BOREALIS

The upper picture shows the numerous coloured rays of a large display. After a while they may break up and gather together in long streamers overhead, as shown in the second picture

The Atmosphere

BY

PETER HOOD

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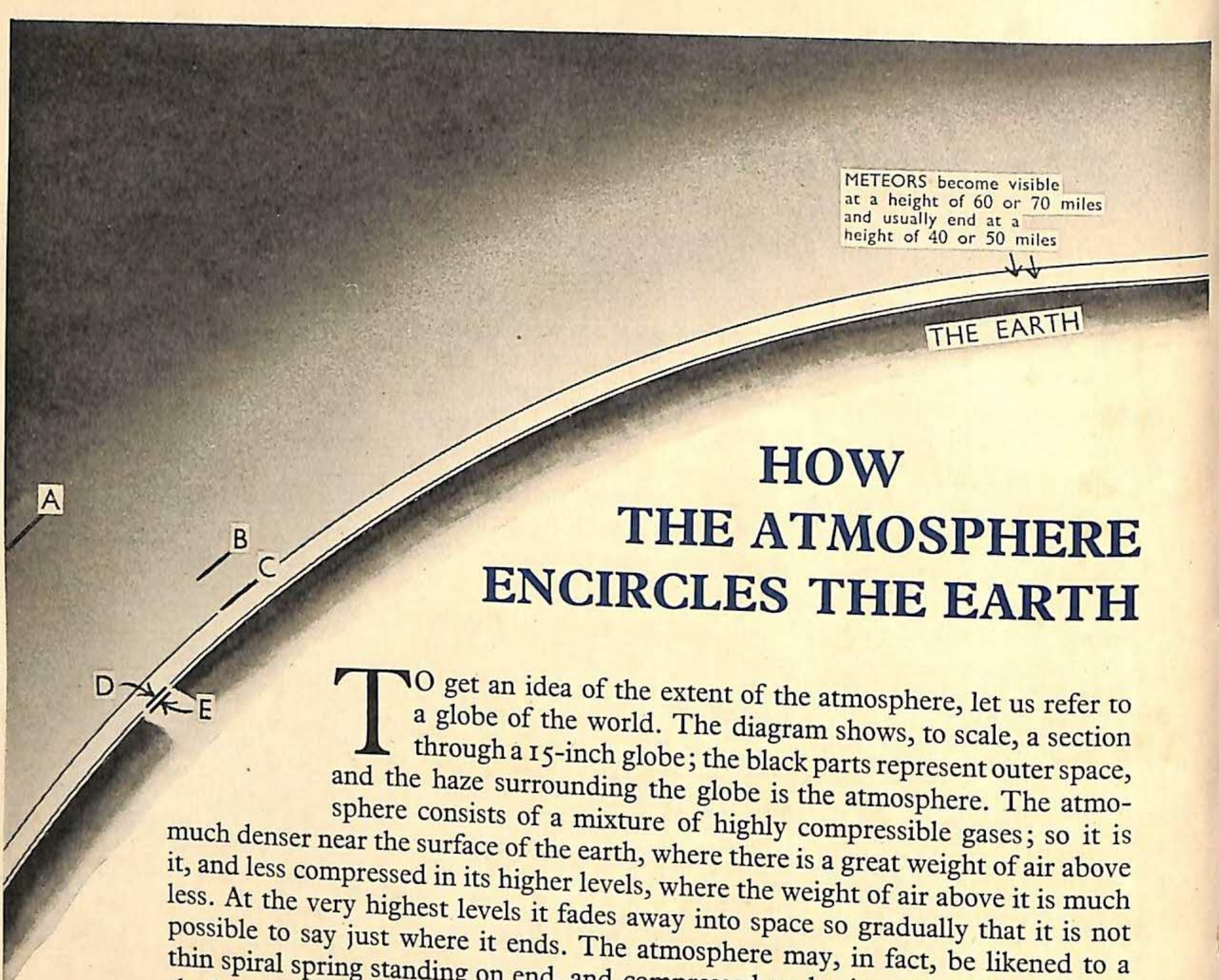
As light as Air

Charles E. Brown

WE often say 'as light as air' as if air were nothing at all; whereas, at the earth's surface the air is quite heavy. Because it is transparent we are apt to forget its presence, yet we soon feel its motion, and when there is a high wind it may blow us over. If we travel on something that moves quickly we find that the air offers resistance. A motor-car or aeroplane must cut its way through the air, and so is streamlined, in order that the air may flow freely round it. It is the resistance of the air that makes the parachute descend slowly. It sails gently downwards because the weight it supports is spread out over its huge canopy, which cannot fall more rapidly because the invisible air is sufficiently dense to resist the motion of so large a surface.

The air we breathe is merely the lower and denser part of the atmosphere which encircles the earth. This air around us we take for granted, without thinking specially about it, yet it is essential to our existence. If we could not breathe we should soon die. But the atmosphere serves other purposes besides: it helps to maintain a fairly even temperature, so that over most of the world it is neither so hot that life is scorched, nor so cold that everything freezes. It acts as a screen to shield us from harmful rays that would otherwise beat down on the earth and make life impossible. It also protects us from the myriads of small fragments called meteors which continually rain down upon the earth from outer space. All this, and much else, will be described in the pages that follow.

We always think of the surface of the earth as being the natural environment for mankind; but there are many dead worlds, like the moon, where, for want of an atmosphere, no human being could live. It is the atmosphere therefore that gives us life and protection; that warms and shields us by night from the fierce cold of outer space; that gives us all the changes of weather, and softens the blinding glare of the sun by day, diffusing and spreading the varied light and colour of the open air.

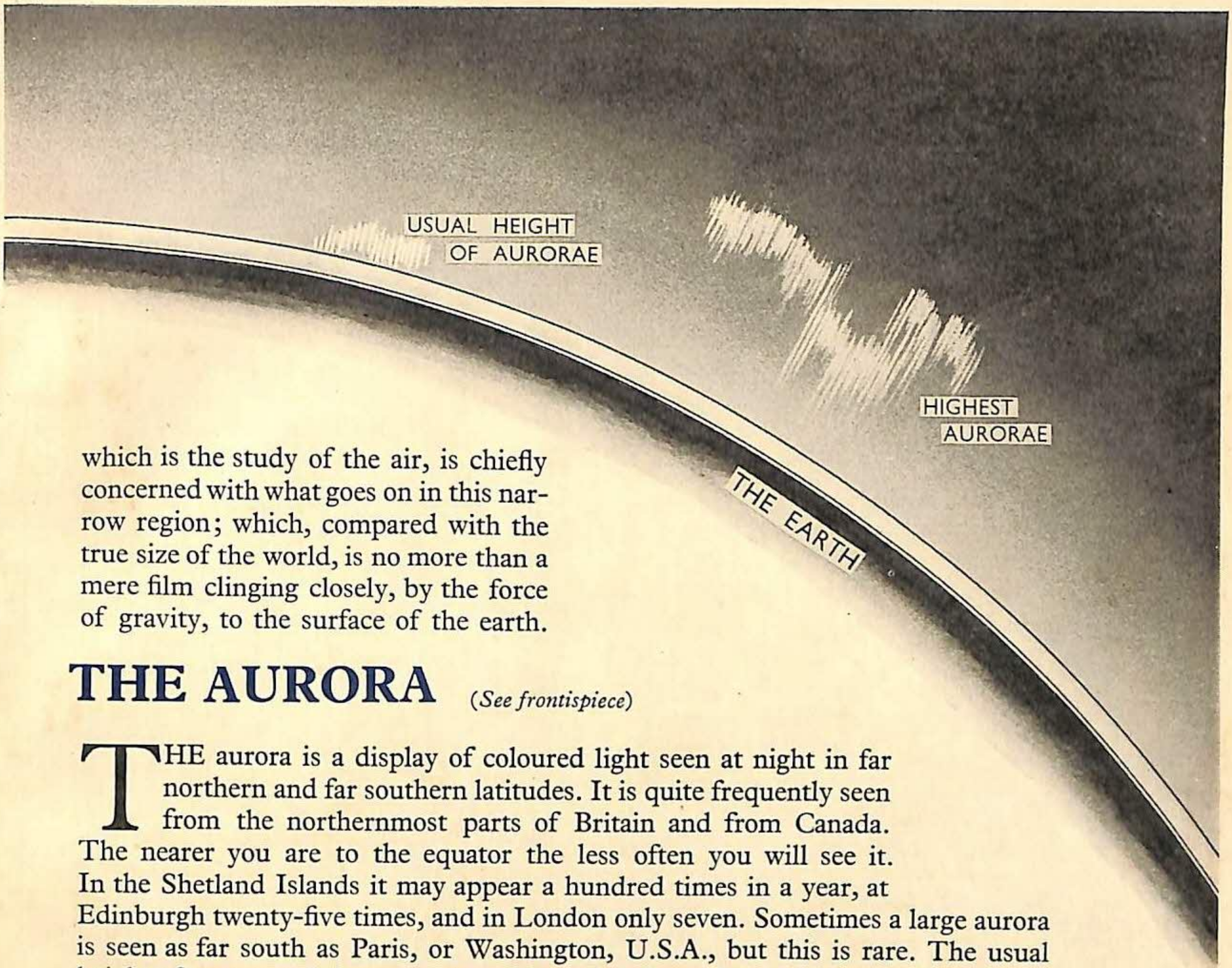

METEORS become visible at a height of 60 or 70 miles and usually end at a height of 40 or 50 miles
THE EARTH
A
B
C
D
E

HOW THE ATMOSPHERE ENCIRCLES THE EARTH

TO get an idea of the extent of the atmosphere, let us refer to a globe of the world. The diagram shows, to scale, a section through a 15-inch globe; the black parts represent outer space, and the haze surrounding the globe is the atmosphere. The atmosphere consists of a mixture of highly compressible gases; so it is much denser near the surface of the earth, where there is a great weight of air above it, and less compressed in its higher levels, where the weight of air above it is much less. At the very highest levels it fades away into space so gradually that it is not possible to say just where it ends. The atmosphere may, in fact, be likened to a thin spiral spring standing on end, and compressed under its own weight, most at the bottom and least at the top.

This falling off in density with increase of height above the earth is easy to understand. There are other differences between the higher and lower levels, however, and it is now known that there are three distinct regions in the atmosphere. The lowest, called the Troposphere, is that with which we are most familiar, the region of the clouds and our changing weather; it extends from the surface of the earth to a height of about 7 miles. This height is greater at the equator and less at the poles. The middle region is called the Stratosphere, and extends from a level of about 7 miles above the earth up to a height of about 50 miles. The highest region is called the Ionosphere, which extends upwards for 600 miles or more above the surface of the earth.

In the diagram, *A* marks the approximate upper limit of the Ionosphere; *B* shows the height already reached by rockets with recording instruments; *C* marks the top of the Stratosphere, about 50 miles above the earth; *D* is the base of the Stratosphere, and *E* is the surface of the earth where we live. It will be seen that the lowest region of the atmosphere is confined between *D* and *E*, which on this scale is represented by a space of only about one-fiftieth of an inch, the two lines being so close together that they appear almost as one line. Yet the science of meteorology,

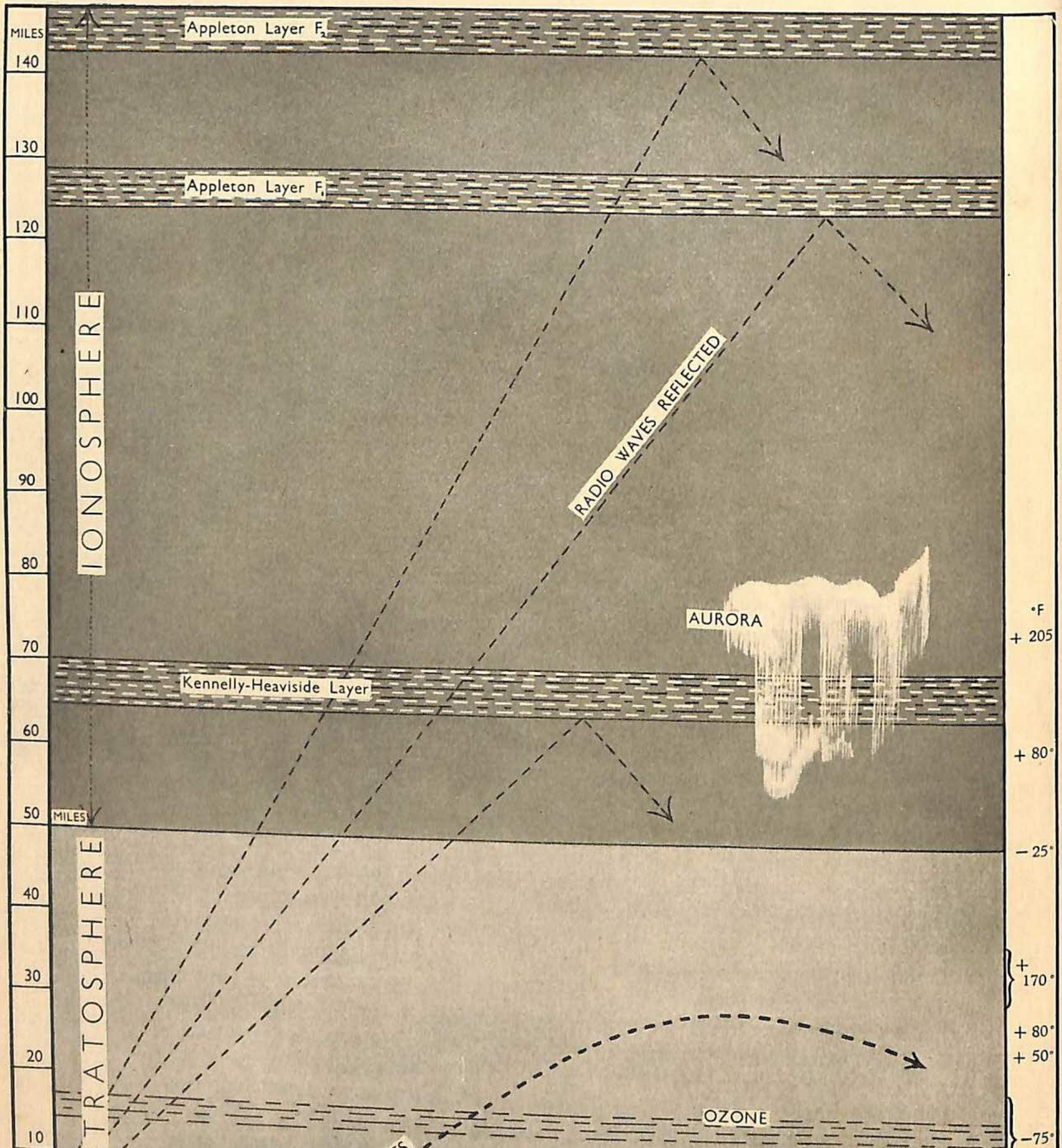


which is the study of the air, is chiefly concerned with what goes on in this narrow region; which, compared with the true size of the world, is no more than a mere film clinging closely, by the force of gravity, to the surface of the earth.

THE AURORA *(See frontispiece)*

THE aurora is a display of coloured light seen at night in far northern and far southern latitudes. It is quite frequently seen from the northernmost parts of Britain and from Canada. The nearer you are to the equator the less often you will see it. In the Shetland Islands it may appear a hundred times in a year, at Edinburgh twenty-five times, and in London only seven. Sometimes a large aurora is seen as far south as Paris, or Washington, U.S.A., but this is rare. The usual height of an aurora is between 55 and 80 miles above the earth, but heights of over 600 miles have been observed. The light we see is an electrical effect: streams of electrically charged particles are shot out by the sun, especially from areas where there are sunspots. When these streams of particles reach the earth they become concentrated towards the north and south magnetic poles, and they excite the air much as the gas in a neon light tube is excited; they also disturb the earth's magnetism. Aurorae are often more frequent about the time of the equinoxes, and they are especially visible during the years when there are many sunspots.

The light appearing in the sky may be merely a vague glow, or it may be like large draperies or curtains in movement. At other times it may be more like the beams of a searchlight, but with many rays, trembling and quivering and changing their position. A large display may last some hours; beginning with a low arc of light along the horizon, numerous vertical rays may develop, making a brilliant spectacle. Golden yellow is the most frequent colour, turning to pearly white in the more brilliant parts, with streaks of crimson and green. When the display breaks up the streamers may gather together almost above the observer, when they seem to point towards one centre. This is an effect of perspective, like railway lines converging towards a distant point, for the rays, which may be 300 miles overhead, are nearly parallel.


MILES
140
130
120
110
100
90
80
70
60
50
40
30
20
10
Appleton Layer F_2
Appleton Layer F_1
IONOSPHERE
RADIO WAVES REFLECTED
AURORA
Kennelly-Heaviside Layer
50 MILES
STRATOSPHERE
OZONE
SOUND WAVES
Radio Station
TROPOSPHERE
Mt. Blanc
Mt. Everest
°F
+ 205
+ 80°
− 25°
+ 170°
+ 80°
+ 50°
−75°

THE HIGHER REGIONS of the ATMOSPHERE

IT is well known that as we climb up a mountain side in the day-time the air becomes progressively colder, despite the fact that we are getting nearer the sun. There are two main reasons for this. First, the air receives the greater part of its warmth from the heated surface of the earth and not direct from the sun. Second, except near the ground, the atmosphere loses by radiation more of the sun's heat than it absorbs. Therefore, on a scorching summer afternoon in England, an aeroplane pilot flying at 15,000 feet may shiver in a temperature well below the freezing point. Even in the hot equatorial regions of the world, mountains over 20,000 feet high are capped with snow all the year round. But the fall of temperature with increasing height does not continue indefinitely. The lowest part of the Stratosphere is uniformly cold; the middle part is warmer than the air near the earth's surface; and the upper part is once more cold. These changes are noted at the right-hand margin of the diagram. Still farther up, in the Ionosphere, the temperature rises again until it actually becomes higher than 212° F.

The pressure of the air also changes with height. It is quite considerable at the surface of the earth where we live, but we do not ourselves feel this pressure because it is exerted in all directions, both inside and outside our bodies. If we climb a really high mountain, however, we find we have to take several breaths for every one we took down below, and every movement is a great exertion. Increase of height brings a steady reduction of pressure; this is another way of saying that the air becomes thinner, more rarified, until there is not sufficient oxygen to breathe.

In Tibet, as well as in the Andes, there are inhabited places where the pressure of the air is not much more than half what it is at sea level. It takes time to become acclimatized to living at heights above 8,000 feet. And when flying at 20,000 feet or over it is essential to have an artificial supply of oxygen. At very great heights the pressure becomes too low for life to continue—we cannot live in a vacuum—so aeroplanes must have a pressure cabin, securely sealed from the outside air, and providing within a pressure high enough for the human body to function properly.

In the lower part of the Stratosphere is found a layer of ozone, a specially heavy sort of oxygen gas. Its maximum density lies between 15 and 18 miles above the earth, and it fades out altogether at a height of about 30 miles. This ozone has the peculiar property of absorbing most of the fierce ultra-violet light which is radiated by the sun. The amount which filters through to the earth is sufficient to kill bacteria that are exposed to it, but is no longer strong enough to be harmful to us. Another thing that happens in the Stratosphere is that big sounds are reflected. Any very loud noise, like a heavy explosion, travels up to a height of some 25 or 30 miles. At this level the temperature of the air is increasing, and this bends the sound waves downwards again, so that they return to the earth, but a long way from their point of origin.

HOW RADIO WAVES TRAVEL

WHEN a broadcasting station transmits, the radio waves first travel in straight lines, like light waves. Short-wave transmissions maintain their direction almost unchanged, but the longer the wave-length the more the waves are liable to be bent or reflected at high levels in the atmosphere. Thus, when there is a mountain between us and the transmitter, we can receive no direct waves; nor can we possibly receive direct waves if we are so far away that the curvature of the earth hides the transmitter. But the waves bent or reflected from high levels in the atmosphere do reach us, and it is these waves which the receiving set ultimately picks up.

In the Ionosphere the air is very rarified, and the radiation from the sun is so intense that many of the atoms of the air become electrified, and are said to be ionized. They lose their outer particles or electrons, and these free electrons go scurrying about, forming a conducting layer for electricity. In this way they build up an effective 'radio' mirror high in the sky, invisible to our eyes, because light waves pass through it. But most radio waves are instantly reflected or turned back to the earth by it, perhaps to be reflected again so as to reach round the earth to distant listeners. There are two principal reflecting layers, and each is liable to some variation in height. They are known as the Kennelly–Heaviside Layer and the Appleton Layer, after the men who discovered them. Only short-wave transmissions can penetrate these layers and travel upwards into outer space; and such waves have been sent to, and reflected from, the moon.

METEORS

IN the Ionosphere the tracks of meteors become visible. Their average tracks are shown by short arrows in the diagram on page 6, and it usually happens that they come some way down into the Stratosphere. Though many of them are like stones, most are no larger than grains of sand; but as they become drawn towards the earth, their speed is so great they would be as penetrating as bullets. Fortunately the air exerts a strong resistance to their motion, and they become vaporized in the oxygen of the air and wholly consumed, so that all we see is a streak of light. Those that are really large are not always altogether consumed on their downward course, and if they fall to the earth, they are called meteorites.

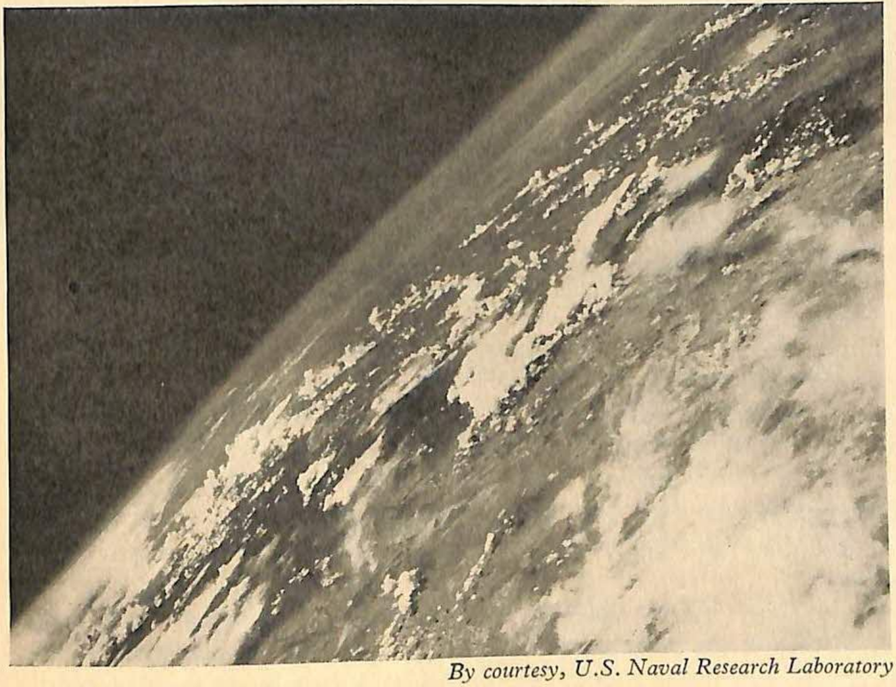
WHY THE SKY IS BLUE

OUT in space there is an inky darkness. It is only to us, inside the atmosphere that surrounds the earth, that the sky seems to be bright. This is because the sunlight illuminates not only the surface of the earth but also the particles or molecules of which the atmosphere is composed. When we look upwards in the daytime, we are really looking at these illuminated molecules. As the molecules have the property of scattering blue light very effectively, the clear sky always looks blue.

When the air at lower levels contains many solid particles which float about as dust, the blue sky becomes whitish, and we call it haze. This is because the dust particles, though minute, are very much larger than molecules, and they reflect all the light, which is white; and so haze may appear silvery in the sunshine.

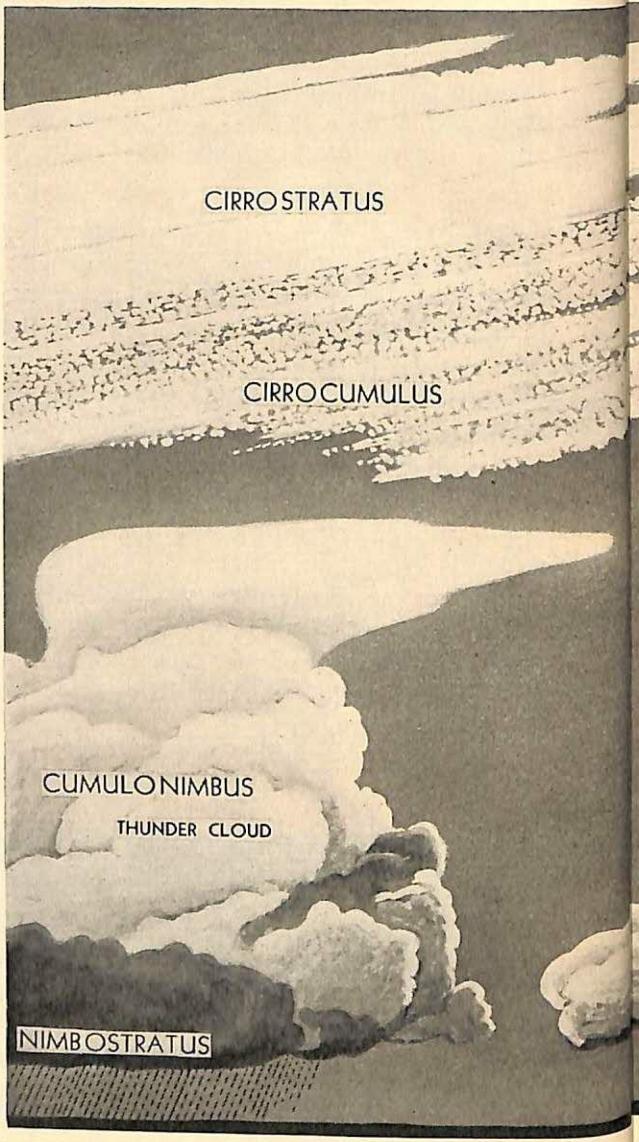
ABOVE THE ATMOSPHERE

ON this page is a photograph taken from a rocket. It shows the earth as it appears from a height of 57 miles. Mountains and clouds appear to have become confused together, and it is impossible to distinguish them separately. The horizon shows the curvature of the earth. The peculiar thing to notice is that, although it is daylight, and the earth below is lit up in the sunshine, the sky is quite black. This is because above the atmosphere the sun is blazing in overpowering splendour in a black sky, with all the stars visible, even at midday. This seems hard to believe until we remember that the stars do not just 'come out' at night: they are above us in the daytime too, but the molecules of the atmosphere scatter and diffuse the light of the sun so that the whole sky looks bright, and we cannot see the stars (unless we look with a telescope, and even then we must know just where to point it). When the U.S. balloon *Explorer II* reached an altitude of 13·7 miles, the sky appeared almost black even in the daytime, having 'the merest suspicion of dark blue' and the sun's rays were 'unbelievably intense'.



By courtesy, U.S. Naval Research Laboratory

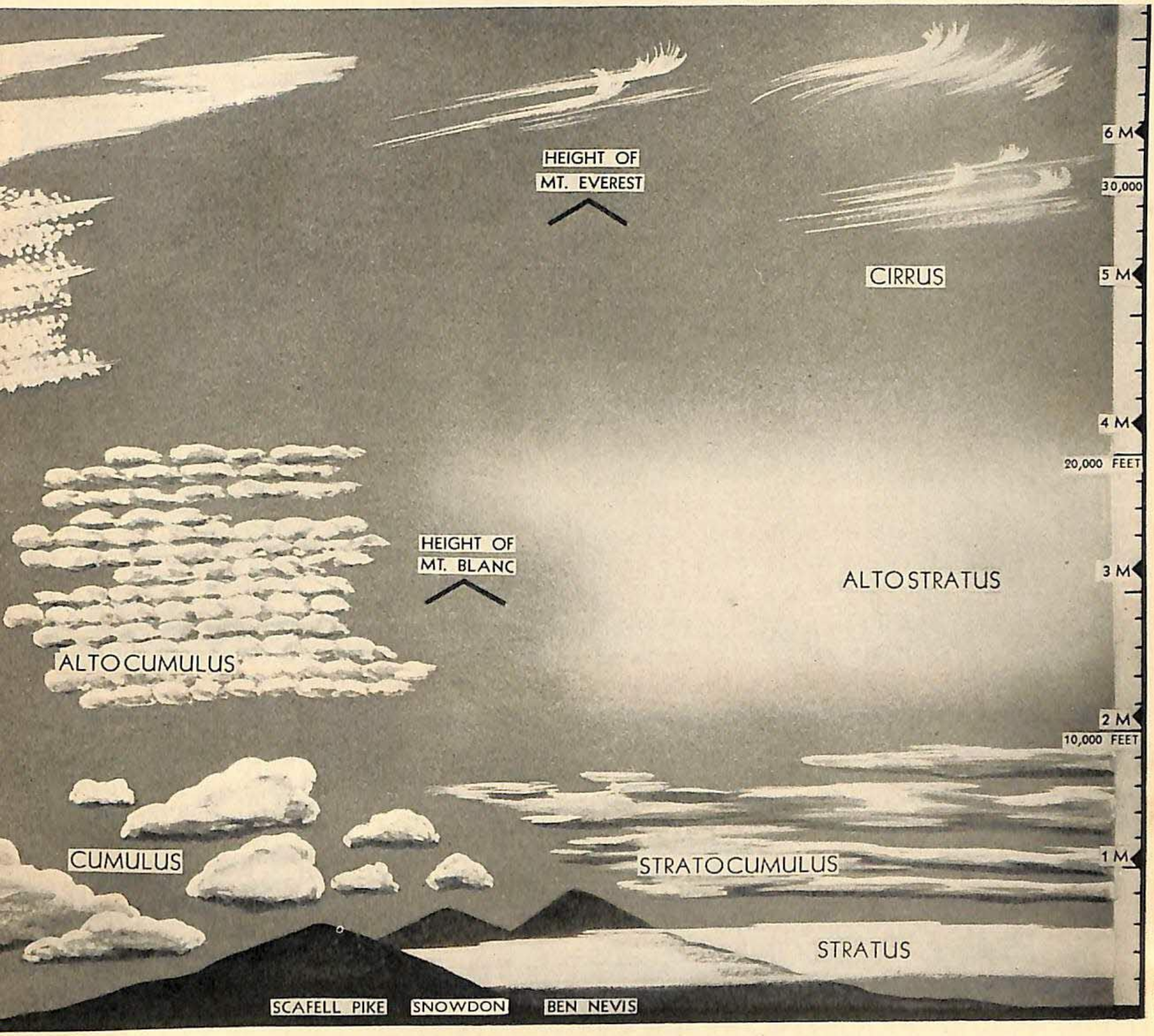
Watching the Clouds



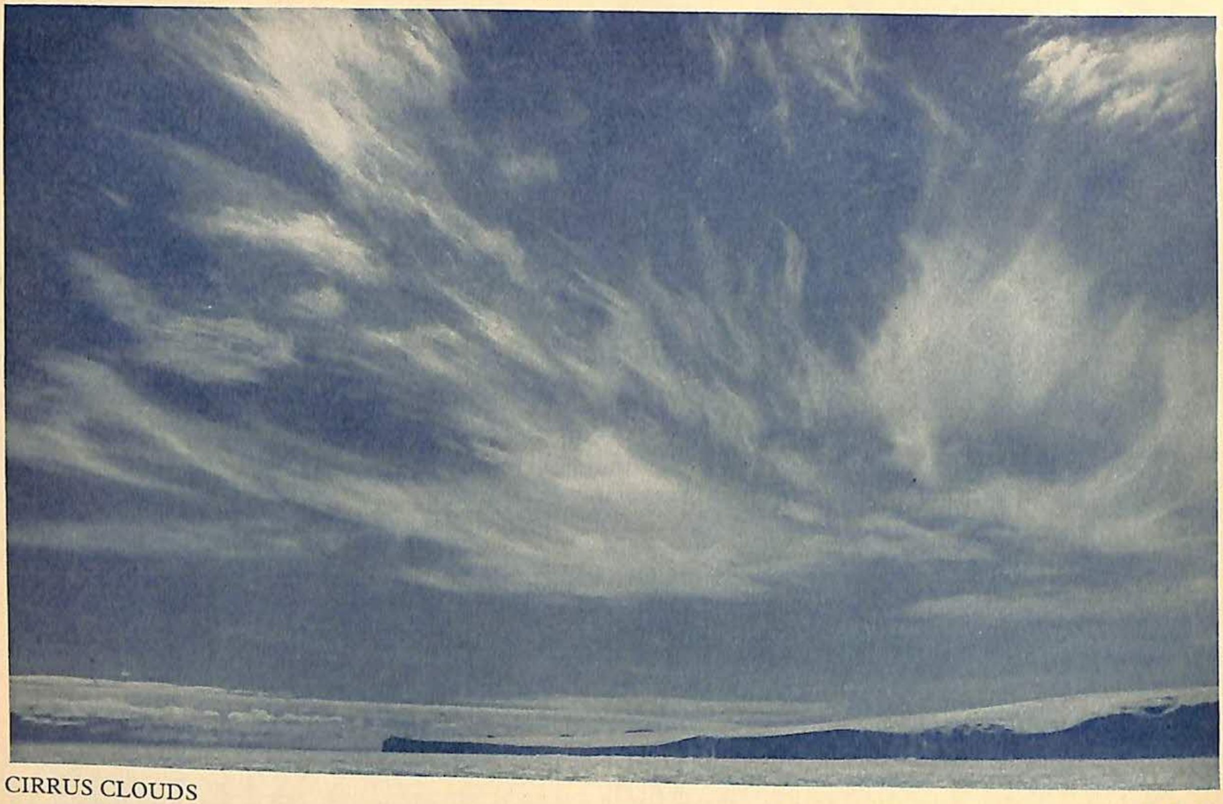
THE sky is always changing and often gives us—at times unexpectedly — magnificent pictures, more brilliant than the finest paintings, of varied composition and colour, light, and shade. For this reason alone we should never fail to notice the ever-moving pattern of the clouds above us, and the interesting effects that are to be seen. But knowing the clouds is of practical use also. The clouds are not just fixed objects, like cut-out pieces of scenery. Apart from their motion in the wind, they are like living things, always in some movement, either growing or dissolving. Each type of cloud is the result of certain causes, and therefore we can tell a good deal about the state of the weather merely by seeing what sort of clouds are present in the sky.

The clouds are the same all over the world. It is not difficult to recognize the main varieties if we distinguish between those at different levels in the sky: high, medium, or low. Often there may be two or more types of cloud visible at the same time, some high and some low. The higher clouds appear to move more slowly, but this is due to their greater distance; in fact, they are probably moving faster, for the speed of the wind is usually greater at higher altitudes. Another remarkable thing is that the lower clouds may be moving in one direction while the higher clouds are moving quite differently, sometimes at right angles to the lower ones.

This diagram shows the ten chief types of cloud, and how they are grouped in three levels always in the same vertical order. The scale at the side is marked in thousands of feet, and also in miles. The mountains of Britain are less than a mile

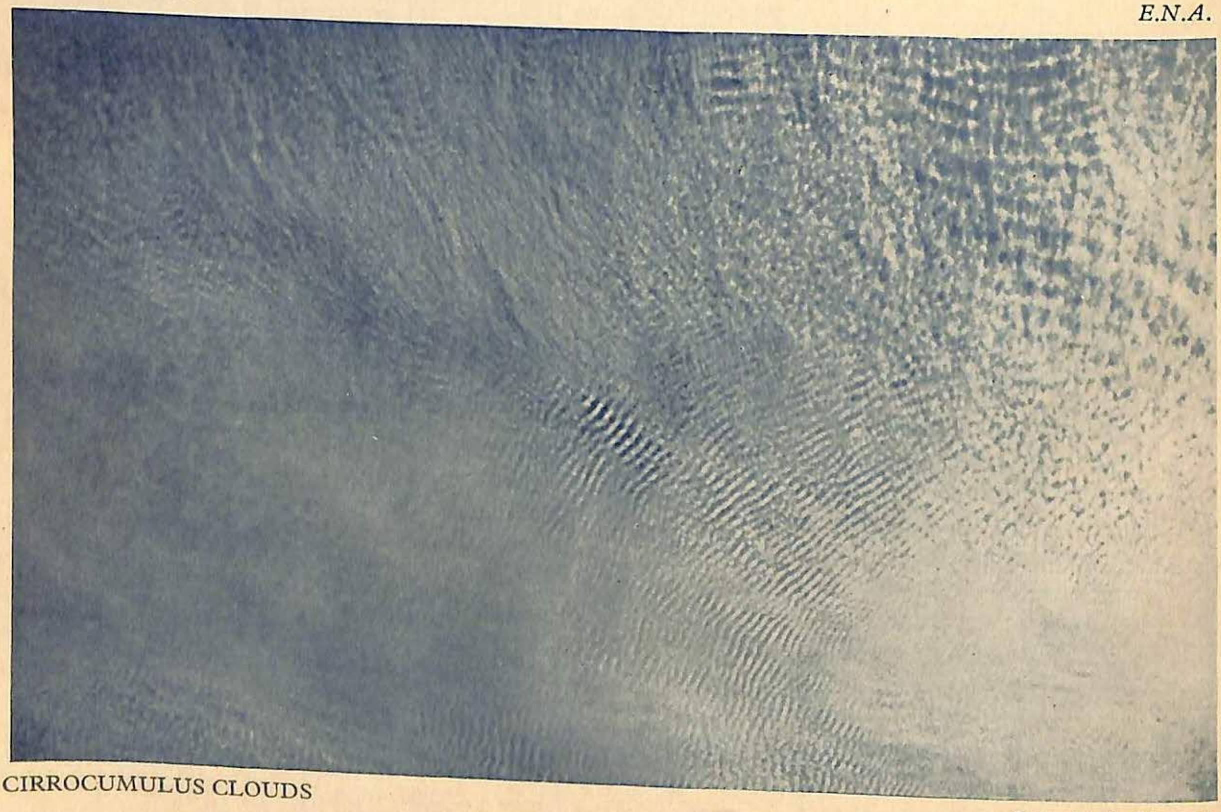


high, whereas Mount Everest (shown by mark) is almost as high as the highest clouds. The high clouds are: CIRRUS, of thread-like appearance; CIRROSTRATUS, a continuous sheet; and CIRROCUMULUS, or mackerel sky, often to be seen on the edges of cirrostratus. There are never any shadows in these high clouds. The clouds of medium height are: ALTOCUMULUS, consisting of bands of small clouds sometimes having slight shadows; and ALTOSTRATUS, a uniform sheet of cloud. The low clouds are: CUMULUS, the commonest clouds, seen on most fine days; STRATOCUMULUS, which forms in long rolls; STRATUS, like fog lifted off the ground; NIMBOSTRATUS, the low dark rain-cloud; and lastly CUMULONIMBUS, the thunder-cloud, which towers up like a mountain and may be as much as five miles high: its anvil-shaped top is a form of cirrus, made up of ice particles.



CIRRUS CLOUDS

E.N.A.



CIRROCUMULUS CLOUDS

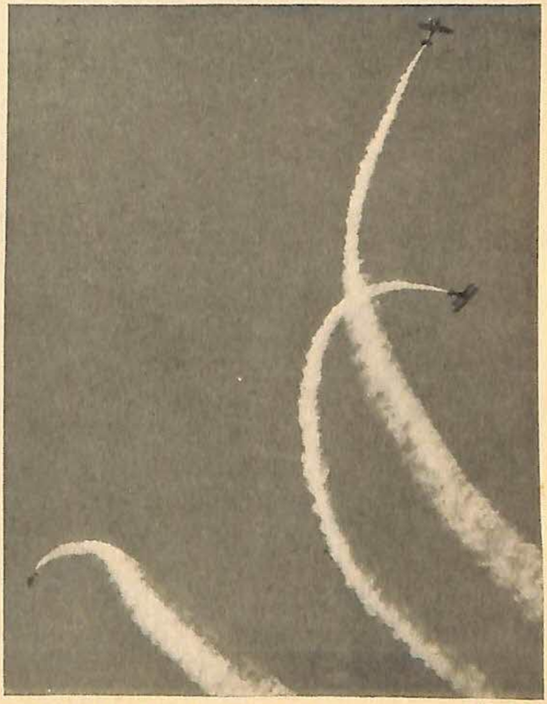
Capt. D. S. Hancock

THE HIGH CLOUDS

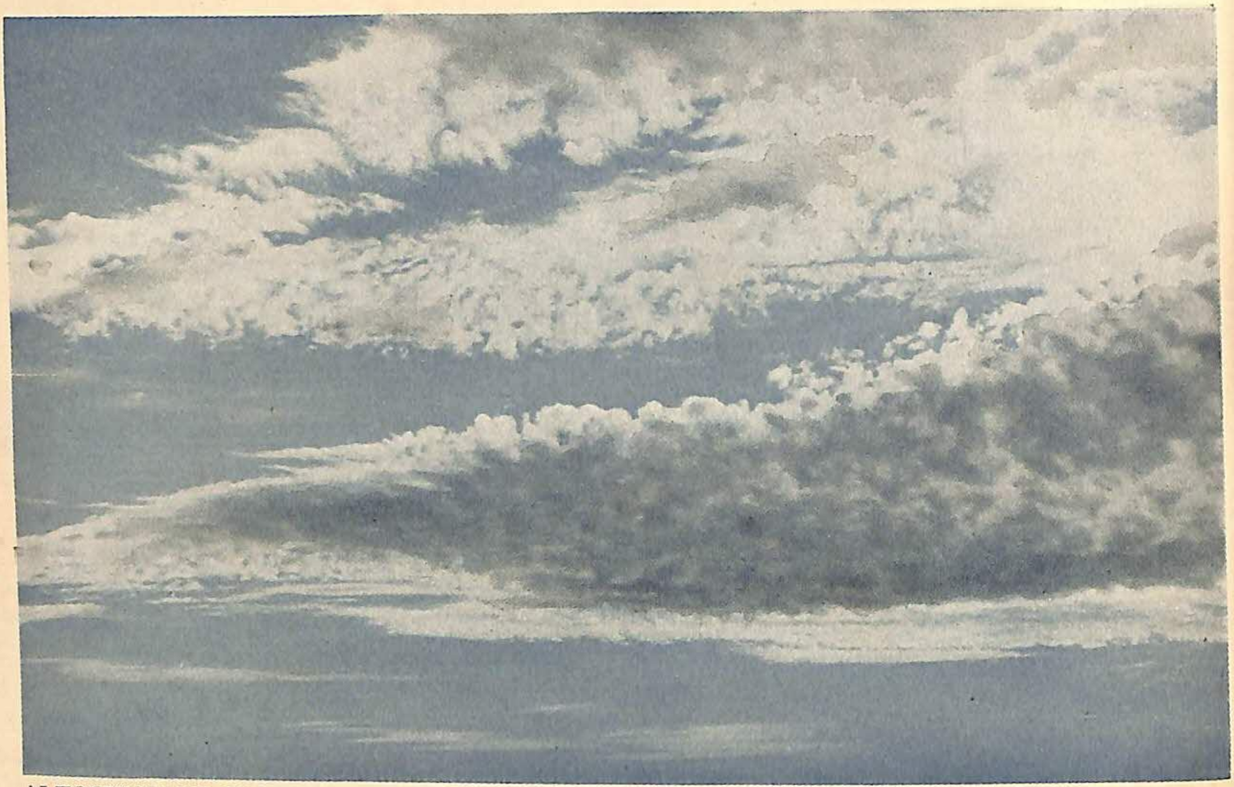
THESE clouds always appear a pure white against the clear blue sky, unless coloured at times of sunrise or sunset. They may be hidden from view when there is much low cloud present. Cirrus often appears like little plumes, or like wisps of cloud with upturned tufts. When there is much of it, and it is spread over a large area, it is easily recognized by its fibrous texture. Its usual height is about 30,000 feet. Even on the hottest day, the temperature at that height is below freezing, and so these clouds are composed of ice crystals. When there is much cirrus cloud in the sky, we should always watch to see if it is increasing in amount; it may remain relatively unchanged; but if it does increase or thicken, this is one of the signs of distant rain approaching. When cirrus cloud spreads more continuously across the sky it forms an unbroken sheet and is called cirrostratus. Some of the fibrous structure may still remain, or it may look merely like a thin veil giving the sky a milky appearance. It is always so thin that the sun and moon are seen through it, and sometimes cirrostratus is in the form of broad bands across the sky. Cirrocumulus is usually a dissolving form of cirrostratus, seen at heights above 20,000 feet. It also often appears in bands across the sky. When these converge towards a point on the horizon, this is an effect of perspective, since the clouds themselves may be more than a hundred miles long. Cirrocumulus consists of white flakes or patches, sometimes globular, but always so thin that there are no real shadows. Often the pattern is beautifully splayed out, like ripples on the sea shore, and this is sometimes called a 'mackerel sky'.

MAN-MADE CLOUDS

A PECULIAR kind of cloud we have all seen is that which forms as condensation trails behind high-flying aircraft. This is not to be confused with a smoke screen because it is a true cloud, even though it is made by man. The trails are due to the condensation of water vapour from the hot engine exhausts. This occurs in temperate latitudes at heights over 22,000 feet in winter, or over 28,000 feet in summer. In very cold climates it may occur at much lower levels.



CONDENSATION TRAILS *E.N.A.*



ALTOCUMULUS CLOUDS *A. M. Strachan*

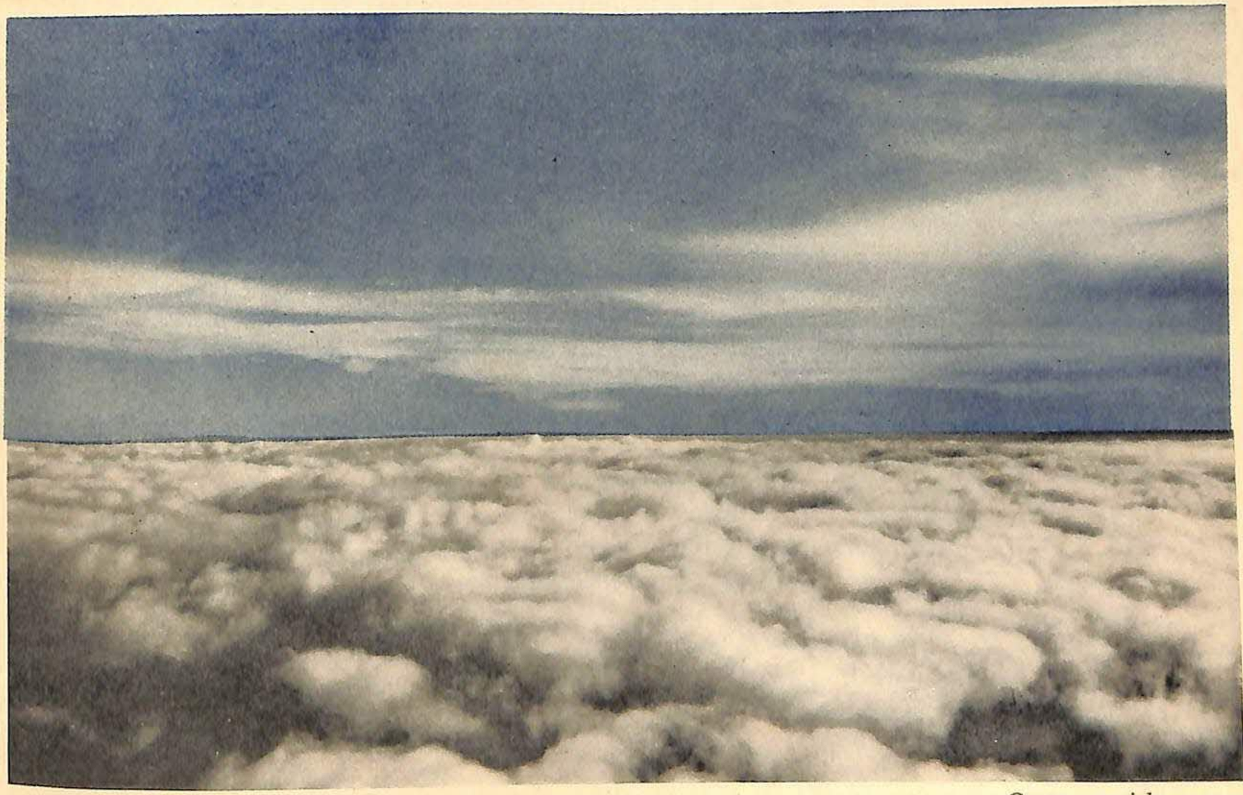
THE MIDDLE CLOUDS

THE clouds of medium height appear in the diagram on an earlier page; they may easily be confused with similar types above and below them, but they have certain points of difference. Altostratus, which cannot be shown well in a photograph, is a structureless even sheet of cloud usually found at a height of about 15,000 feet. It is lower as well as being rather thicker than cirrostratus. It may be thick enough to hide the sun or moon, but sometimes either may be seen vaguely through it, as if being viewed through sheets of ground glass. When this happens we say the sun has a 'watery look', and usually the appearance of this cloud is a sign that rainy weather is approaching. The photograph above is of altocumulus, which is like cirrocumulus, only the cloudlets appear larger, and they are often not a pure white against the blue sky but have a slight grey shadow on the sides away from the sun. The cloudlets, therefore, appear slightly more thick and rounded; their height is usually between 10,000 and 20,000 feet.

ALOFT IN THE AIR

ABOVE the clouds it is always sunny in the daytime. The picture below shows a sheet of stratocumulus seen from above. All the clouds look brilliant because over three-quarters of the sun's radiation is reflected upwards and outwards into space when it strikes the surface of clouds. Only the remaining fraction penetrates downward through the thickness of the clouds; and it is much diffused in the process, so that to anyone below, on the ground, the sky would be overcast and it would seem to be a dull day.

When flying above a continuous cloud layer, we are out of sight of the world, and all seems strange where the landscapes are made of clouds. Before aeroplanes were invented, the only way of ascending to such a height was by a balloon, and the vast silence of these lofty regions is best appreciated from a balloon. Even ordinary noises, however, do sometimes penetrate above the levels where the lower clouds float. At the beginning of this century, the pilot of a balloon which had reached a great height once remarked to his companions that he had heard a cow: they promptly reassured him, thinking he must have become light-headed, but presently they all heard the cow mooing loudly. It is now known that sounds do ascend vertically a long way if unimpeded. When a balloon descends, the silence of the upper levels is first broken by sounds which float up from the earth. An experienced balloonist has described how, descending towards a wood, he heard the wonderful harmony of 'the combined singing of thousands of birds'.



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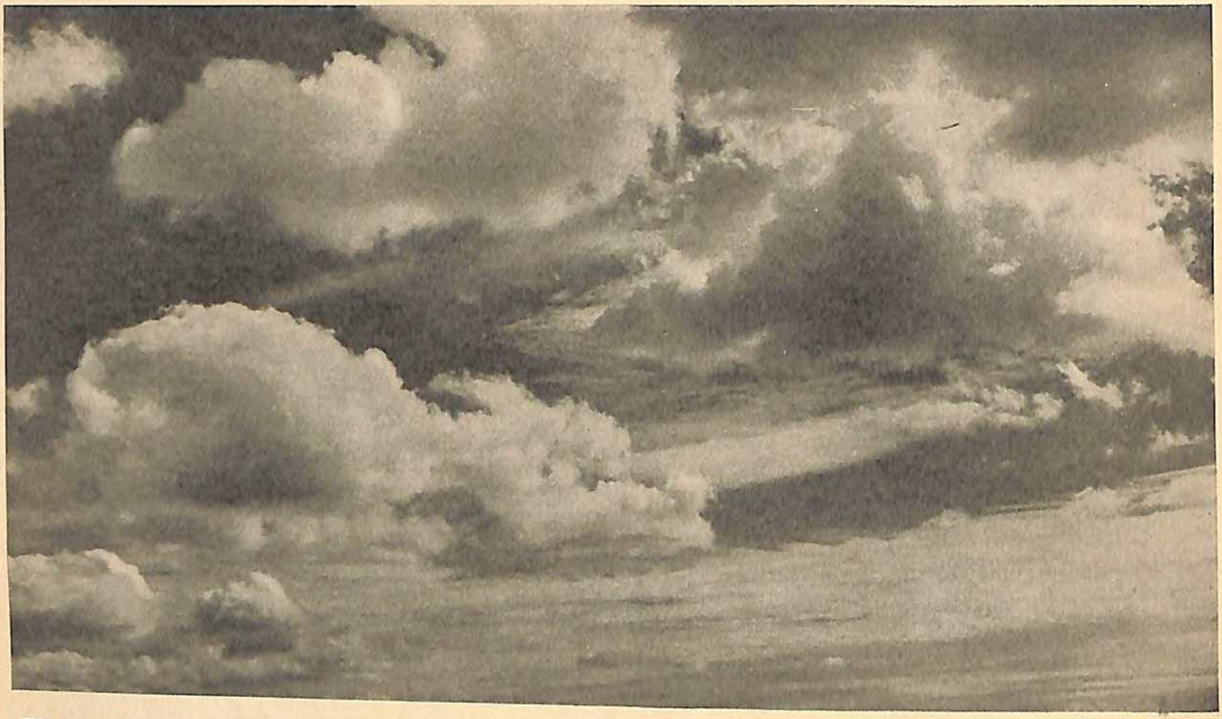


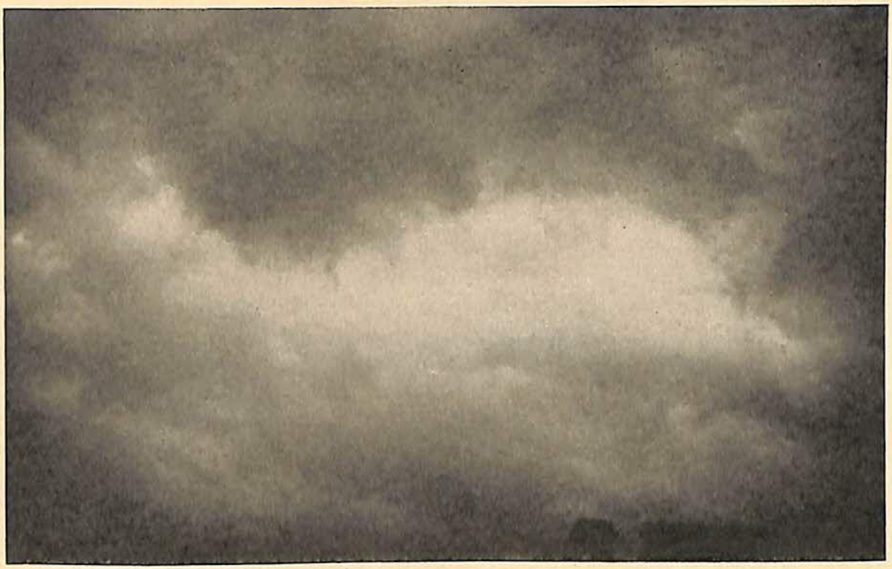
The lower clouds here are CUMULUS: *the high clouds are* CIRROSTRATUS

Cleveland Hood

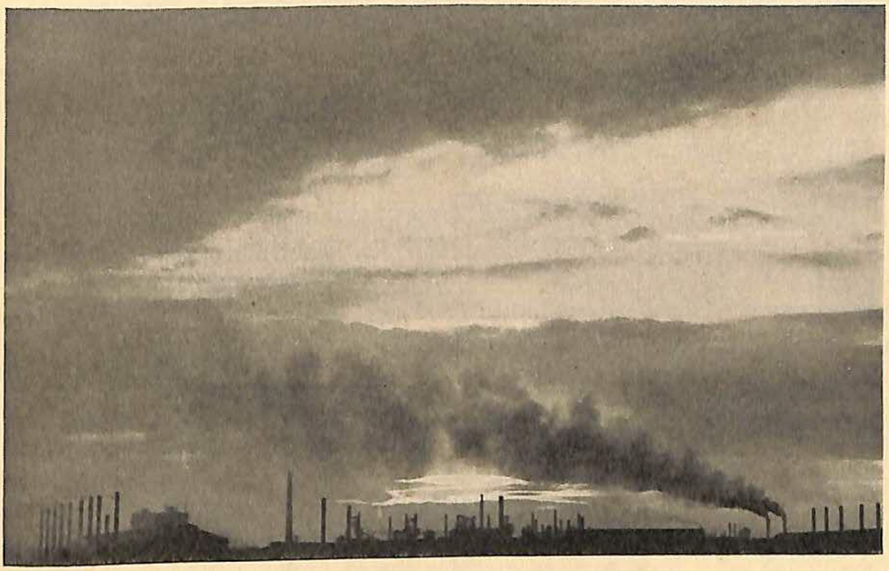
THE LOWER CLOUDS

ON these pages are pictures of clouds which, being nearer to us than those already described, are easy to observe and distinguish. The most common are cumulus clouds, which have flat bases and well-rounded tops. Their bases are at a uniform height, as a rule between 2,000 and 4,000 feet, though the effect of perspective sometimes makes them appear at different heights. The clouds themselves grow upwards, puffing out more and more until sometimes their tops may be double this height. Most cumulus clouds on a fine day, however, are relatively small and disappear by evening; or if they are large enough to persist, they may develop into stratocumulus, generally in the form of long rolls of cloud, with some clear sky between or sometimes in rolls so close together that they form a continuous sheet of cloud, the thickness from top to base being between 500 and 3,000 feet. Such a cloud sheet, seen from above, is shown on the previous page. When it is thick and continuous, it cuts off the sunshine from the earth below, and in winter may last for days at a time, making the weather dull and depressing. Nevertheless, it has some advantage in that it acts like a blanket around the earth, retaining heat, especially at night, which would otherwise be dissipated into space. In fact, when the cloud sheet is thick, the temperature may remain almost constant night and day.

Stratus is simply a flattish sheet of cloud, like fog, but not resting on the low ground. In calm weather we may see it hiding the upper part of a mountain while the lower part is clear. When we climb a mountain, the

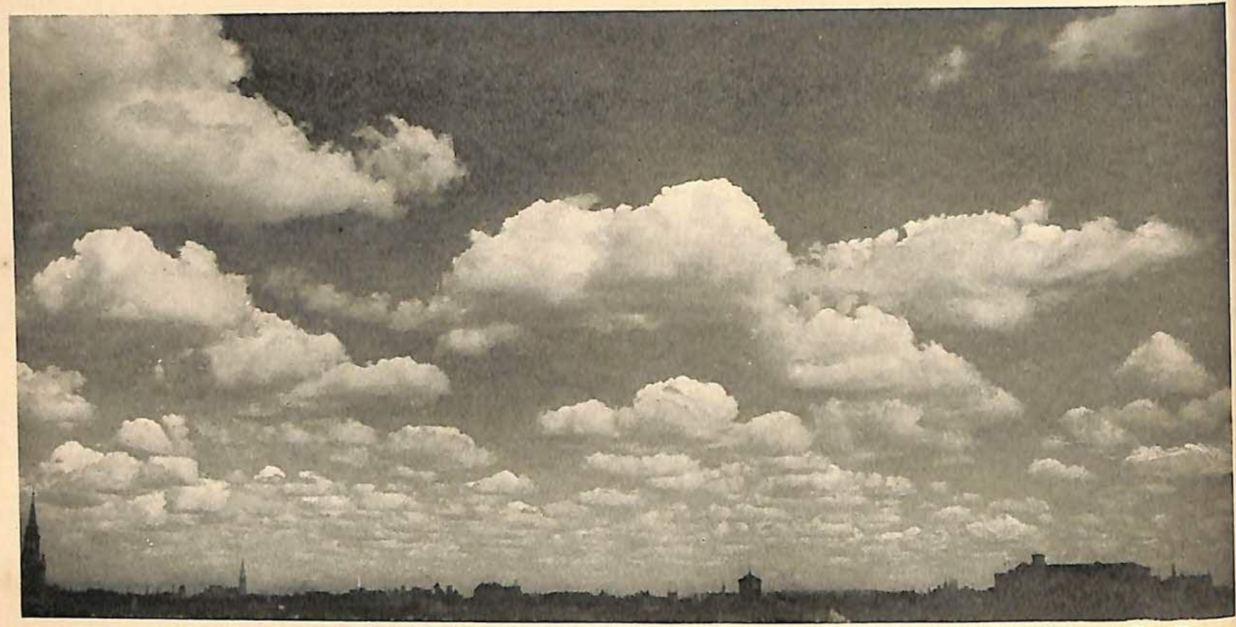


NIMBOSTRATUS,
THE RAIN CLOUD
Royal Meteorological Society



STRATOCUMULUS
The smoke has nothing to do with the cloud, but shows the direction of the wind
Cleveland Hood

bases of the lower clouds seem near, and if we climb high enough a cloud may envelop us. We shall then seem to be in a sort of fog, which is really all that a cloud is, and our only danger will be that it is easy to lose direction. When stratus cloud is broken into irregular patches, carried along in the wind, it is called fractostratus, the typical 'scud' of bad weather. The low dark grey cloud from which rain is falling is called nimbostratus. It usually has a ragged edge when seen against the background of lighter clouds, though it is itself of smooth unbroken texture. The broken scud travels along beneath it.



Fox Photos

CUMULUS CLOUDS

WATER IN THE AIR

AIR is a mixture of gases. It consists of 78 per cent. nitrogen, about 21 per cent. oxygen, and has traces of carbon dioxide and other inert gases. Air also contains a variable amount of water vapour, the invisible gas which is taken up into the air when water evaporates. Growing plants absorb some of the carbon dioxide, and give out oxygen; we ourselves absorb oxygen, and breathe out carbon dioxide. Because of the complicated balance of nature, however, the proportion of the gases in the air remains steady, with the exception of the water vapour.

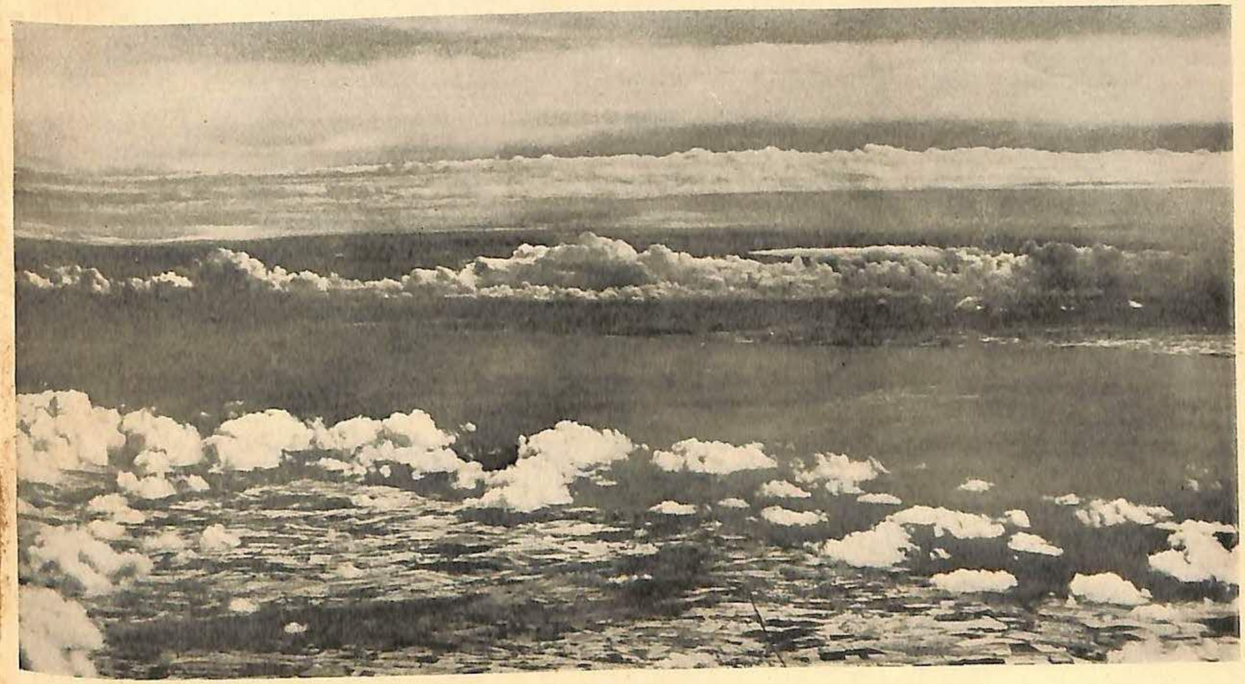
The amount of water vapour which the air can hold depends on the temperature at the time: if the temperature is high, the air is capable of holding a great amount of water vapour; if the temperature is low, the air can only hold a small amount. This is one of the principal facts in the study of weather. The amount of water vapour which happens to be present in the air is usually expressed as the 'relative humidity'. Let us suppose that the amount is only half what it could be at the existing temperature, then the relative humidity would be 50 per cent. If the temperature falls, though the same amount of water vapour is present, the relative humidity increases because the air can no longer absorb up to the same maximum. If the temperature goes on falling, there comes a time when the humidity will be 100 per cent. This is called the saturation or dew-point; and if the temperature still continues to fall, the air can no longer hold all the water vapour it contains, and the moisture condenses, usually on to minute particles of dust in the air. Thus we get a cloud, or a fog; or it may be the moisture will condense as dew on grass—the reason is the same.

HOW CLOUDS FORM

THE formation of clouds in the air is due to the condensation of water vapour. When the sun heats the earth's surface, some areas, such as lakes or woods, are slow to heat. Other areas, like houses and roads, or bare rocks, heat quickly. This unequal heating affects the air, and over a very warm surface there will develop a large though invisible 'bubble' of hot air. Presently this will break away and rise, and as it does so the surrounding air will rush in, giving the sudden short breeze that we so often notice on a hot day. The bubble of warm air expands as it rises, and expansion causes cooling, so there is a limit to its upward progress. The air may contain much moisture in the form of invisible water vapour, and if it rises sufficiently high it may reach a level (called the condensation level) where, because of the lowered temperature, the dew-point is reached and cloud begins to form. The commonest type of cloud, called cumulus, is formed in this way. In reality, there may be several successive bubbles of air, and therefore several clouds, often in a line because the wind carries them from their point of origin. All other types of cloud are also due to condensation, but in different ways, such as when warm air flows upwards over cold air, or when water vapour turns directly into ice to form cirrus cloud.

THIS picture shows the English Channel from a height of 20,000 feet. Warm air is rising from the land on each side of the Channel and condensing into cumulus clouds, while no such clouds are forming over the sea, which is colder. The edge of the clouds follows the coast line; the lines appear different because they are seen in perspective, the clouds being over 2,000 feet above the surface.

The Times



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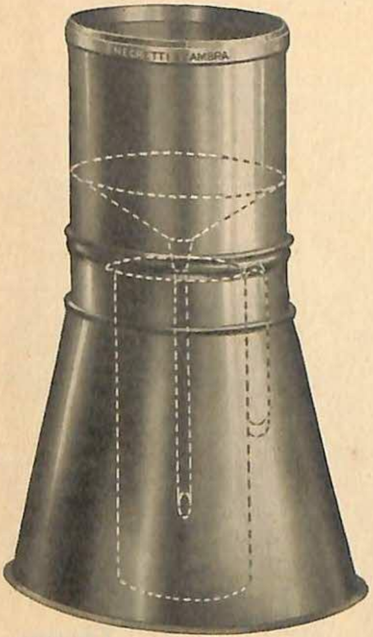
RAINFALL

SIZE OF DROPS	RATE OF FALL	
· $\frac{1}{6000}$ inch		FOG OR CLOUD
· $\frac{8}{10,000}$ inch	$\frac{1}{2}$ inch per second	
· $\frac{1}{1000}$ inch		
• $\frac{8}{1000}$ inch	$2\frac{1}{4}$ feet per sec.	LIGHT DRIZZLE
∘ $\frac{2}{100}$ inch		RAIN
○ $\frac{4}{100}$ inch		
○ $\frac{6}{100}$ inch	17 feet per second	
○ $\frac{8}{100}$ inch		
◯ $\frac{19}{100}$ inch	26 feet per second	

WITHOUT rain there would be little or no life, as in the great deserts. We are dependent upon rain for several reasons. Where there is no water, plants cannot grow, so there is no food for animals. We require for ourselves a pure and unfailing supply of drinking-water, the farmer depends on sufficient rain for his crops, and many industries have to be placed where fresh water can be obtained in abundance. All this water, to begin with, must come from rain. So the amount of rain which falls at any given place is important.

We have seen how clouds are formed by condensation, but this alone does not mean that it is going to rain; something else has to happen. The small droplets of condensed water vapour which form the clouds are at first very small indeed, as you will see from the diagram. They grow larger, as well as more numerous, if more and more water vapour is condensed from the air, and eventually some of them become very large in comparison with the tiny specks of moisture which make up the cloud. These larger droplets accumulate round very small solid particles, which may consist of ice, dust, or chemical matter, floating in the atmosphere, and in this way globules of rain are born and soon begin to fall because of their weight. While falling inside the cloud the globules sweep up more and more of the condensed water vapour, and if the cloud is very thick they may finally become a trifle over one-fifth of an inch in diameter. This is the largest possible size for a raindrop to have when it reaches the ground. Resistance of the air breaks up any bigger drop into smaller droplets as it comes down from the clouds. When raindrops are formed they do not necessarily fall to earth at once. The rising currents of air in a tall cloud are often strong enough to carry up even the very largest drops for many thousands of feet. When such a rising current suddenly ceases the big raindrops which it has taken aloft may all fall together in a tremendous downpour. This is known as a cloudburst. All rain in any quantity is produced by the lifting of damp air, which can happen in several ways. The damp air may be caused to rise through being heated, and thus made lighter, by contact with sun-warmed ground. It may be forced upwards by mountains or hills. Or masses of warm and cold air may meet: in that event the warm mass, being the lighter of the two, climbs bodily over the heavier cold air, as illustrated on a later page, and in so doing has its water vapour condensed into water drops. The only rain that can fall from unlifted air is slight drizzle.

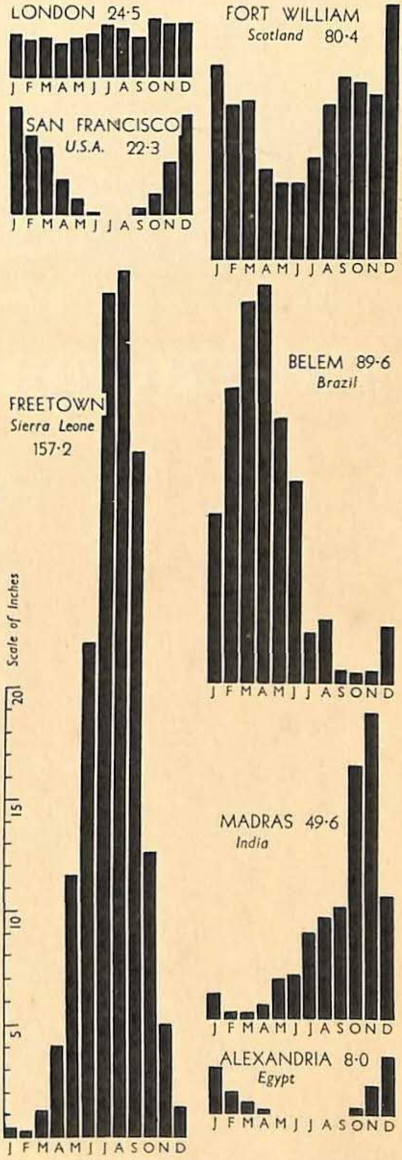


THE RAIN-GAUGE
By courtesy, Negretti & Zambra

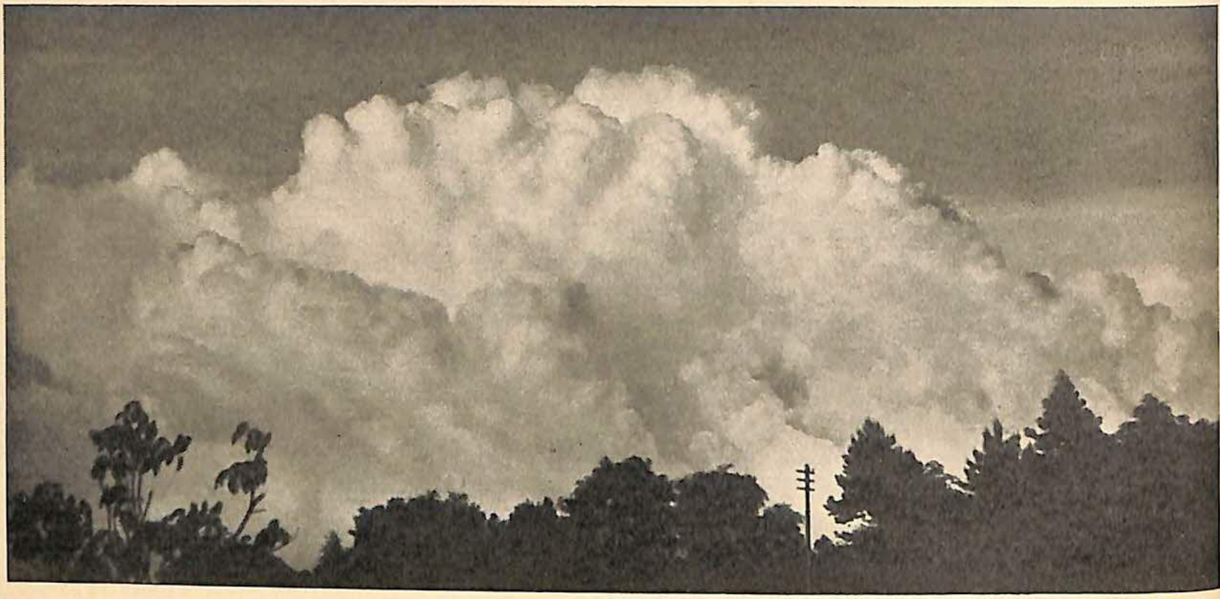
The amount of rain which falls at any given place is easy to measure. All we need is a rain-gauge, a simple apparatus of standard size, so that measurements in different places may be comparable. It is set on an open level plot with its upper rim a foot above the ground. Its open top is 5 inches in diameter, and inside is a funnel which collects the rain into a bottle or measure. Rainfall is sometimes called precipitation because it includes dew, hoar frost, wet fog, and hail or snow (when melted); and the total amount is measured in inches or millimetres. In wet weather, many places may get over ½ inch of rain in a day. This may not seem a lot, because ½ inch of water at the bottom of a bucket would not look very much: but we have to remember that it is a ½ inch depth of water over everything, roofs, roads, trees, fields, and this actually means about fifty tons of water per acre. When there is a very heavy downpour, over 1 inch of rain may fall in a quarter of an hour.

By keeping daily records it becomes possible to say what the rainfall has been for any month or year. The total number of inches at any given place, during the whole year, is called the annual rainfall. By taking the average over a long period the mean annual rainfall is obtained. This is useful when comparing different climates, though we have to remember that the figures for any particular year may differ greatly from the mean. Records of monthly totals reveal which months have the greatest rainfall. In the British Isles there is no marked seasonal change, though the winter months and August are the wettest. Many climates have a wet season and a dry season, and rain may come mainly in the winter or mainly in the summer, or at some special season, as the records on this page show.

The heaviest rainfall in the British Isles occurs on the hills and mountains of the west, because the prevailing winds are from the west or south-west. The humid air, as it rises over the hills, is forced to give up its moisture as rain. In the mountains of Wales, in the Lake District, and in the Highlands of Scotland, the mean annual rainfall sometimes exceeds 125 inches; and one of the wettest places is The Stye in Cumberland, with a mean of 175 inches. Many of the eastern parts of England are relatively dry, with a mean of about 25 inches, and one of the driest places is Dagenham in Essex, with 19·3 inches. Other parts of the world show much greater extremes. At a place called In Salah, in the middle of the Sahara desert, it only rains about once in ten years; whereas in Assam, at Cherrapunji, 905 inches once fell in a single year, and the mean figure is 428 inches.



MEAN MONTHLY RAINFALL

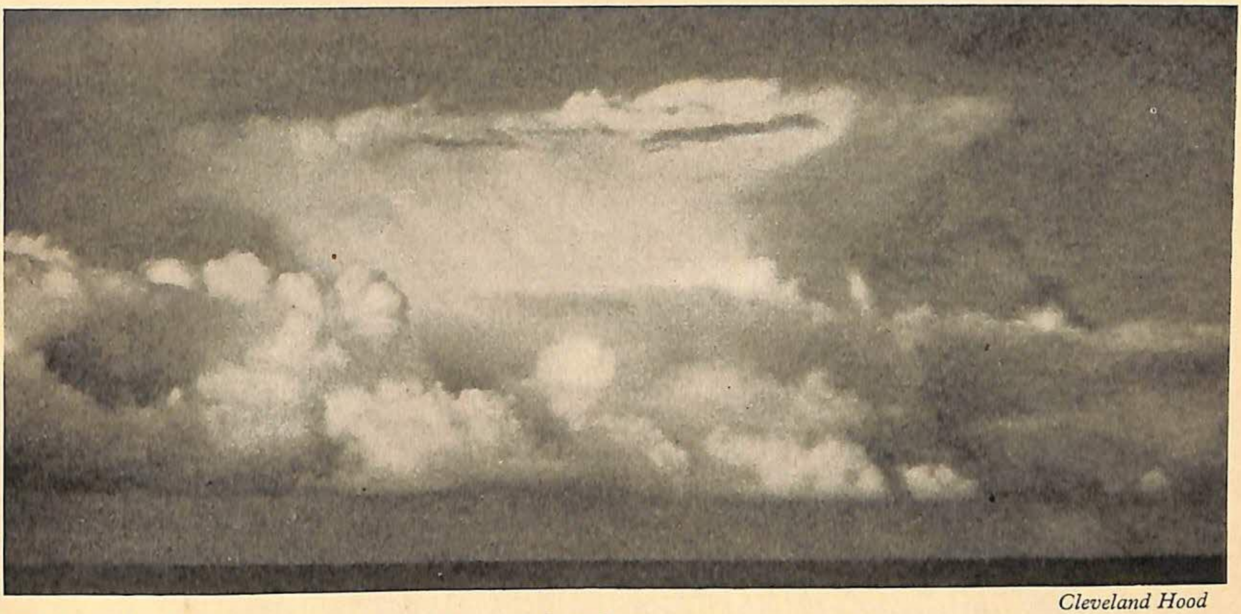


CUMULONIMBUS: *a thunder-cloud beginning to develop* *Cleveland Hood*

THE THUNDER-CLOUD

ON earlier pages we have described the chief types of cloud to be found in the upper, middle, and lower levels of the atmosphere. The type of cloud called cumulonimbus is lord of them all. It is the thunder-cloud, which rises up majestically to build 'castles in the air', and often extends to very great heights, through all the levels at which most of the other clouds are found, until it may be several miles high. In its early stages of growth it is not much different from the ordinary cumulus cloud, but its expansion and development are seen to be much more rapid. When it begins to grow big, as in the picture above, it appears more turbulent than cumulus. And at its greatest development there is one feature that is unmistakable: its highest part develops into a broad white fibrous mass, usually of anvil shape. When this is seen, it generally means that thunderstorms or thundery showers are breaking out or will soon do so.

Thunderstorms often seem to be a sequel to hot weather, especially since the most severe storms always occur in summer. But in fact we may get several days, or even weeks, of fine, settled, and really warm weather without any sign of thunder. When the air is very dry near the ground and warm to a great height, as often happens in settled, fine, summer weather, no thunderstorm can form, and there may even be no clouds. But if the air is damp near the ground and grows rapidly



Cleveland Hood

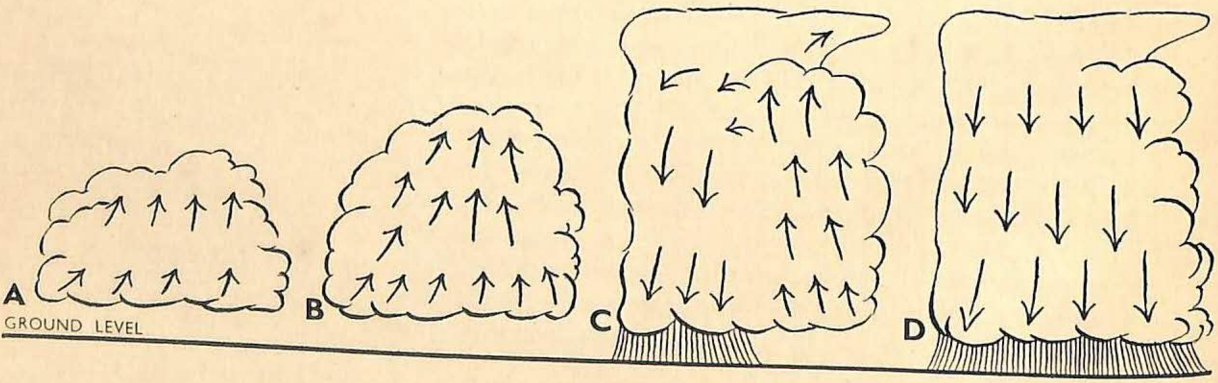
Thunder-cloud drifting out to sea: note the anvil-shaped top

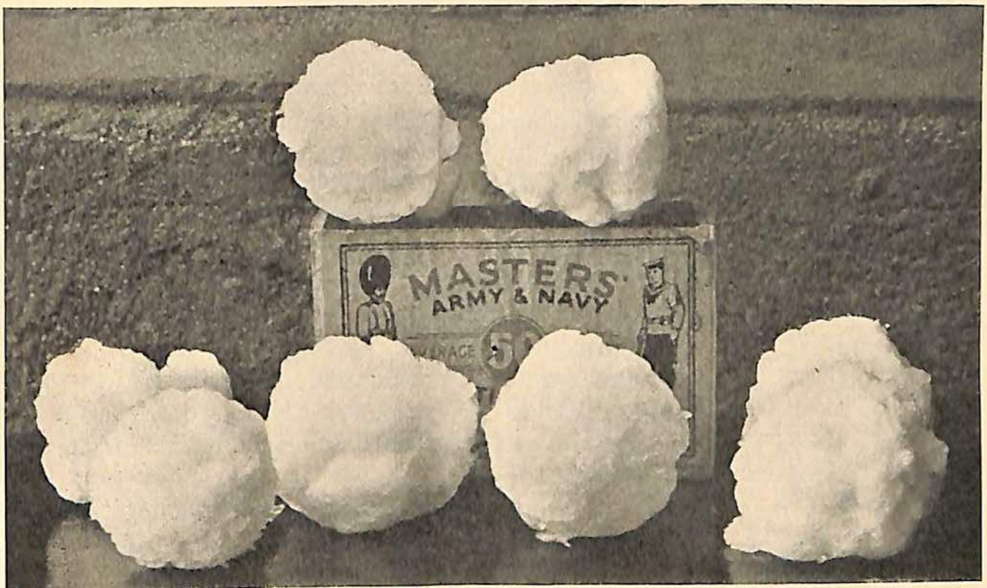
colder with increasing height, then the atmosphere is in what is known as an 'unstable' condition, and thunderstorms or heavy showers will tend to break out, particularly during the afternoon of a day when the land has been strongly heated by morning sunshine. For the explanation we have first to consider what happens when ordinary cumulus cloud is forming. In dry or moderately damp rising air, the temperature falls at the rate (called 'lapse-rate') of about 5½° F. for every 1,000 feet of ascent. But sooner or later there comes a stage at which the amount of water vapour in the rising air is just enough to saturate it with invisible moisture. Any further ascent will cause the water vapour to condense into liquid water. In the process of condensation, heat (known as 'latent' or hidden) is set free for warming the air. The effect of this warming is to reduce the rate at which the temperature falls with increasing height to about 3° F. for every 1,000 feet of ascent. If the temperature of the surrounding air falls faster than 3° F. for each 1,000 feet, the damp air will rise freely through the atmosphere and rain can form: if the cooling much exceeds 3° F. per 1,000 feet conditions become favourable to the development of thunderstorms. Thunderstorms may also result from a steepening of the lapse-rate due to the arrival of cold air in the upper atmosphere over a layer of warm air beneath.

The Thunder-Cloud *(Continued)*

The thunder-cloud starts by several ordinary cumulus clouds growing until they join together as one big cloud, *A*. It may be as much as 3 miles high and 5 miles across. The upward currents continue, as more and more water vapour is condensed and the cloud grows ever higher. The process is too complicated to describe in detail, but we see in the diagram the result of this continued upthrust and growth. The whole cloud, *B*, becomes enormous and may be clearly recognized as a thunder-cloud. The rising air, called the updraught, ascends more swiftly, with a speed of 20 or 30 miles per hour, though occasionally there are speeds of over 60 m.p.h. in the middle of the cloud. This carries the growing cloud, *C*, up to still higher levels and it is the immense vertical thickness of the cloud which makes it seem so dark when we view it from below. At this stage a few big spots of rain may fall, and then soon after, beginning from the rear of the cloud, the upward current is reversed. The raindrops have increased in size until they are no longer supported by the updraught; they come rushing down and bring the air downwards too. We feel a cold gusty wind accompanying the rain, and there may be hail, and at this stage there may be thunder and lightning. The whole huge thunder-cloud, *D*, if we could see it from a distance, now shows its most characteristic feature: the upper part is a broad white feathery mass of a different texture from the rest, and is generally of anvil shape. Here the droplets have turned to ice, because of the low temperature at that height. The lower part of the cloud empties itself of the rain or hail, and in time it dissolves or breaks up, while the high part, or anvil, drifts away to become altostratus or cirrostratus. In a storm there may be several thunder-clouds in different stages of development.

In most parts of the British Isles thunder is heard, on the average, on five to fifteen days in the year. In central, northern, and eastern England the frequency is higher, and is greatest in an area from Nottingham and Lincolnshire in the north to Essex and Suffolk in the south, where it may be recorded on as many as twenty to twenty-five days in the year. In many parts of the world the average is enormously higher—Buitenzorg, Java, for example, has an average of 322 days with thunder in the year.





HAIL-STONES *from Hillingdon, near Uxbridge, Middlesex* *J. F. Smart*

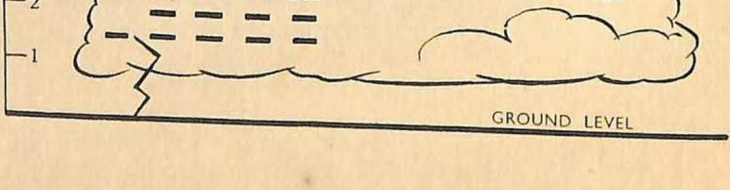
HAIL

THERE are three kinds of hail. One kind consists merely of frozen raindrops, which fall as small pellets of clear ice. A second kind is made up of soft white ice, like tiny snowballs. Both these varieties of hail occur most often when the weather is cold. The third kind, on the other hand, usually comes on hot days with thunderstorms, when uprushing air carries raindrops into lofty regions of the atmosphere where the temperature is far below freezing-point. Up there the drops are changed into ice. On falling to warmer levels below they pick up coatings of water and of water vapour mixed with air, which by contact soon freeze on to them and increase their size. They may then get caught in another uprush of air from the ground and be swept again into the intense cold of the upper atmosphere, there to receive a further coat of ice at once. This process may be repeated ten or even twenty times, until the accumulated weight of ice is too great to be supported by the rising air and the hail-stones crash to earth. On rare occasions they may be as large as cricket balls and do immense damage, smashing the thickest glass, piercing corrugated-iron roofs, and killing human beings and animals so unfortunate (or so unwise) as to be exposed to the icy bombardments from the skies. If such hail-stones are sliced through they are found to be made up of alternating layers of clear ice (condensed water vapour frozen) and white ice (frozen raindrops mixed with air), rather like the skins of an onion; and a count of the number of these layers tells us how many upward and downward journeys the hail-stones have made in the clouds before descending to the ground.

LIGHTNING

LIGHTNING is a huge electric spark, and we see the flash almost instantaneously. The thunder is the noise it makes, but as sound takes time to travel we always hear thunder after the flash. The speed of sound in air is about 1,100 feet per second (roughly 1 mile in 5 seconds). If, therefore, we count the seconds between seeing the flash and hearing the thunder, we shall know how distant is the lightning. As the flash itself is of great length and may have many extensions, the thunder may continue as a long rolling noise, which goes on reverberating among the clouds. Though it may sound frightening, it is quite harmless. Fork lightning is the name given to the flashes which we see, and sheet lightning is the reflection on distant clouds of fork lightning that is hidden from view.

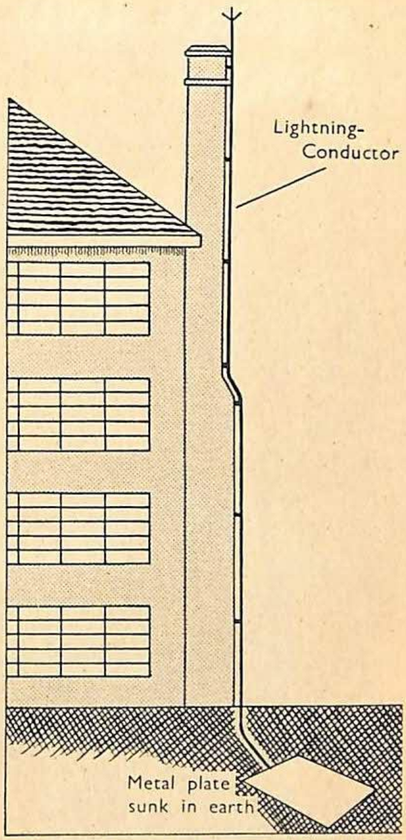
Objects can be charged with electricity. If a glass rod is rubbed with a silk handkerchief both will receive electric charges, one positive and one negative. The water drops, in their ascent and descent through the thunder-cloud, generate large accumulations of positive and negative charges in a rather similar way. The top of the thunder-cloud has a strong positive charge, and the base or lower part has a strong negative charge. In a heavy storm, a huge spark, in the form of a lightning flash, will jump between these differently charged parts of the cloud, or from part of one cloud to part of another cloud that is near. Or sometimes a lightning flash may leap down to earth. When this happens, the lightning has a tendency to strike anything that sticks up or is higher than the surroundings. An open field is a bad place to be in, for man or animal. Sheltering under a tree is even worse, because a single tree is a prominent projection and, if the lightning strikes, it will not only damage the tree, but will endanger any person beneath it. One should also keep away from any wire fencing. It is safer to be in a wood where no particular



tree is higher than any other. It is safest to be in a ditch or other depression, or inside a house, provided we keep away from a fireplace. The lightning flash represents electricity at a pressure of millions of volts, and if it strikes a building it will seek the shortest way to earth. This is generally by the chimney; or tiles may be ripped off as the flash seeks its way downwards.

Telephone and electricity lines, and radio sets with an outside aerial have earth connexions as a protection against the effects of thunderstorms. Church towers or other high buildings are usually fitted with a copper rod called a lightning-conductor. This serves two purposes: first, it carries off any electrical charge from the earth, and so neutralizes any charge in the clouds above. This discharge may sometimes be seen as an electrical glow around the top of a lightning-conductor, or above the mast of a ship. It is then known as St. Elmo's fire. Secondly, if lightning does strike, it is instantly carried to earth by the copper conductor, which is connected to a metal plate in the ground. In this way the flash is carried off harmlessly, without doing damage to the building. There may be thousands of flashes in a single large storm, most of them seeking their way to earth.

The crackling noises in radio receiving sets, called atmospherics, are caused by lightning. We do not directly hear thunder beyond a distance of about 10 miles, though this is exceeded in exceptional cases. Lightning is a frequent cause of forest fires, the burning of one tree setting fire to others. If we happen to be very near a lightning flash we may notice the peculiar smell of ozone, which forms when any powerful spark passes through air. For all its erratic destruction lightning does do one useful thing: it forms an oxide of nitrogen out of the air. This is carried to the earth by the rain, and nitrogen compounds are very valuable fertilizers.

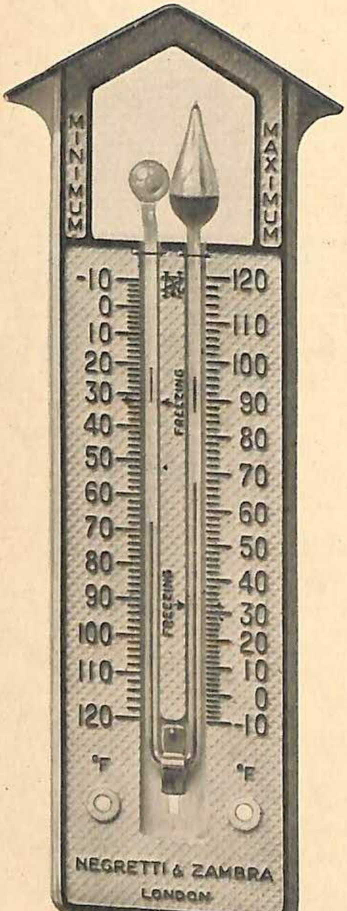


A LIGHTNING-CONDUCTOR

FROST AND SNOW

WE have already seen how air near the ground may become so chilled at night that water vapour is condensed as dew. If the temperature is below freezing, the invisible water vapour turns directly into ice crystals, and we may awake in the morning to find everything white. This is hoar frost, and it is most apt to occur on a clear night when the earth rapidly loses heat by radiation. At such times we may find that the condensed moisture on the inside of window panes has frozen into beautiful traceries of leaf-like patterns. The thickness of ice on ponds depends partly on the severity of the frost and partly on the length of time the frost continues. Rivers do not usually freeze because water in motion does not readily turn to ice. The sea does not easily freeze for the same reason, and also because the freezing-point of salt water is lower than that of fresh water. When water freezes into ice, it increases in volume by a small amount; ice is, therefore, lighter than water and forms on the surface, and a piece of broken ice floats, like an iceberg. When water freezes in pipes, it increases its volume in just the same way: this expansion often breaks a pipe, though the burst may not be noticed until the ice thaws.

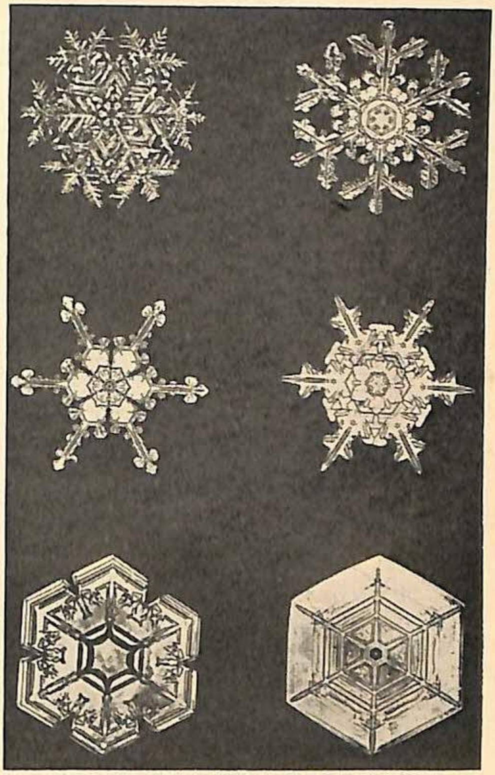
Frosts are much more common in some parts of the British Isles than in others, being least frequent in the south-western coastal regions, and most frequent at places inland, where there may be ground frost on over 100 nights in the year. Local conditions vary, and a valley where cold air collects may be colder and have more severe frosts than a hill top. Sometimes it is said that there have been 'several degrees of frost' overnight. This means that the temperature has been so many degrees below the freezing-point, 32° F. Thus, 22° F. would be 10 degrees of frost. Temperatures below zero only occur rarely in Britain. But Braemar in Aberdeenshire recorded −10° F. on 14 Nov. 1919, and −17° F. on 11 Feb. 1895.



By courtesy, Negretti & Zambra

We may often see in gardens or greenhouses a thermometer which indicates the maximum and the minimum temperature. This type is called Sixe's, after the name of the inventor. As will be seen in the picture, the thermometer has two scales; and on each side, above the column of mercury inside the tube, is a small sliding needle called an index. When the mercury rises, as on a hot day, the right-hand index is pushed upwards; later, when the mercury falls, the index stays where it is, and its lower edge marks the maximum temperature reached. In a similar way, on the left-hand column, another index marks the minimum temperature which usually, though not necessarily, occurs at night. The sliding indexes are made of steel, and so the thermometer may be reset daily by drawing them down to the mercury again by means of a small magnet. For official records, which have to be very accurate, separate thermometers are always used for recording the maximum and minimum readings, as described at the end of this book.

Raindrops are turned into hail-stones when they are carried into a part of the atmosphere where the temperature is below freezing-point. If water vapour condenses into cloud when the temperature is already below freezing-point it turns directly into small ice crystals. As the crystals are very spiky they soon join together in bundles, and these bundles are the snowflakes which drift gently to earth. The individual crystals are six-sided, and remarkable for their beautiful pattern and symmetry, yet no two have ever been found exactly alike. They vary in size from about one-hundredth of an inch across, to nearly one-quarter inch, and their thickness is usually about one-tenth of their width. They cannot often be examined closely because they require magnifying to be seen properly; and very often when snow is falling it is damp and melting. Sometimes in very dry cold weather, however, it is possible to see single large crystals falling on the ledge outside a window pane. They stay just long enough to be recognized before they begin to melt, and if they are large enough we may see the beautiful pattern without any magnifier.



SNOW CRYSTALS MAGNIFIED

By courtesy, U.S. Weather Bureau: W. A. Bentley

Since snow consists of ice crystals, and we know that ice is heavy, we may wonder why snow does not fall more quickly. But snowflakes are mostly air—each is a mere network of crystals—and so has little weight. This also accounts for the fact that, when animals are buried in the snow, they are not suffocated. Because the snow is not really solid but contains much air, it acts like a blanket, and the Eskimo in his snow hut can be quite warm. Even our flowers in the garden may be safer when left covered with snow: if we remove the snow, the frost may wither them, but if we leave them covered, they are protected from the hardest frosts. When snow falls in quantity it makes an even white layer over the earth. The thickness of the layer, in inches or in feet, represents the amount of snowfall; but it must be measured at a level spot, and not where the wind has swirled the snow into deep drifts. When snow falls into a rain-gauge it has to melt before it can be measured; and, because its bulk consists mainly of air, 3 inches of snow will give only about $\frac{1}{4}$ inch of water when melted in the rain-gauge. The exact proportion varies. Sleet is snow which has partly melted as it falls to earth.

FOG OVER FIELDS AND VILLAGE *Aerofilms Ltd.*

FOG

FOG is merely cloud on the ground. If it is thin it is called mist. Normally it consists of condensed water vapour, just like an ordinary cloud; but quite thick fog may also be formed of solid particles due to smoke, and in towns fog is usually a mixture of both types. When no fog is present, distant objects may sometimes be seen imperfectly owing to haze. This is something quite different. It is due to the reflection of light from dust particles, of the sort we see floating in the air when a beam of sunlight shines into a room. Showers of rain clear the air, and so we often see farther after rain. The actual distance seen, called the visibility, is of importance to airmen and seamen, and all forms of transport. It is usually expressed by a scale ranging from dense fog, in which objects at 55 yards are not visible, to excellent visibility when objects at 31 miles are seen. Mist or haze is defined as occurring when objects are no longer visible at a distance of 2,200 yards; and fog, when this distance is 1,100 yards or less.

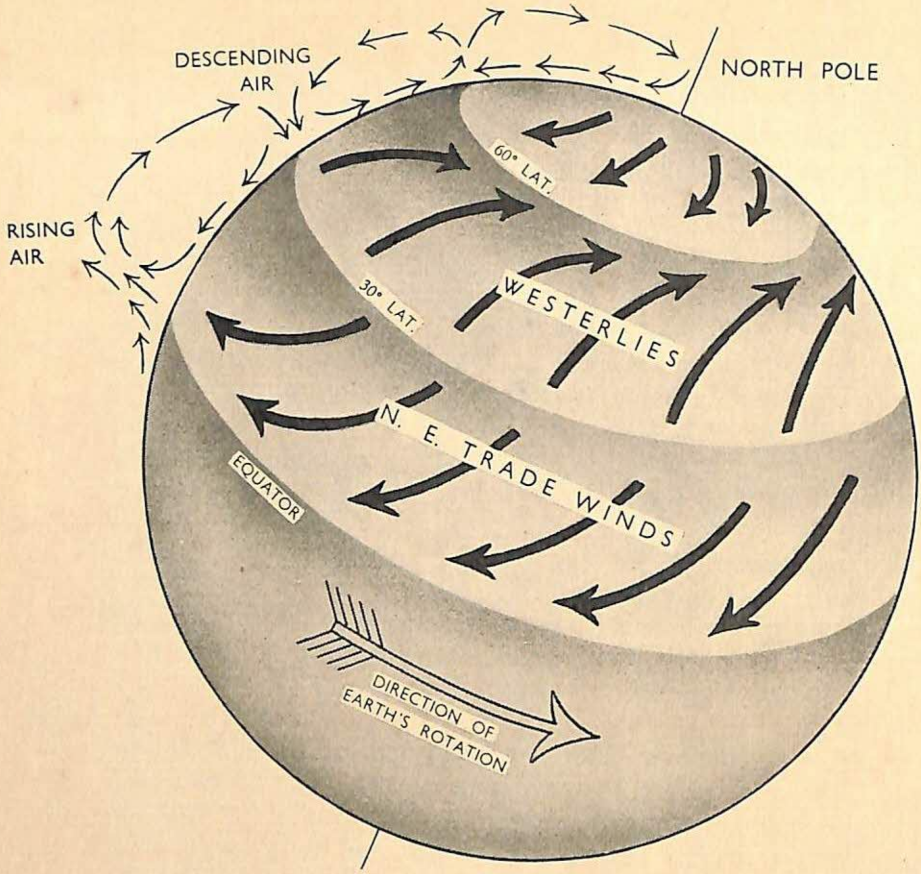
Fog is apt to form in calm weather whenever the temperature of the air falls below dew point, and there are several ways in which this may happen. On a clear night, the earth may lose heat rapidly by radiation, and the air in contact with the ground may be chilled and dew will form, especially on grass. If the temperature of the ground falls very considerably, a much thicker layer of the air which is resting on the earth will become chilled below the dew-point, and some of the invisible water vapour will be condensed into fog. Such fog often has no great depth, and is sufficiently shallow for us to see the moon or the brighter stars when looking straight upwards at night. Just as warm air always rises, cold air always tends to sink. So fog is apt to collect in hollows or fill a valley. In the daytime the heat of the summer sun soon disperses it; but in winter the sun is low and only appears for a short time, and the fog, in the absence of wind, may persist and grow more dense. When this occurs, the temperature of the air does not fall the higher we ascend. On the contrary, the air is colder where the fog is, near the ground, and is actually warmer at a level of 1,000 feet or so. This is called an 'inversion'. Smoke from chimneys will not rise through the cold air to any height, but instead becomes mixed up with the water fog, giving town fog its murky colour. As this makes it still more difficult for the sun's rays to penetrate, the fog may persist over the town for some days, even when the open country around has been cleared by the sunshine. In central London, about half the possible sunshine in winter is cut off by fog and smoke.

The other ways in which fog may form are not always so obvious or so persistent. Two currents of air at different temperatures may cause a fog when they come together and mix. Or a warm, humid current of air may become chilled by passing over a cooler land surface or a cooler sea, and a fog will be formed. Heavy fog-banks in the seas off Newfoundland develop because a warm current of humid air from the south flows over a cold sea current from the Labrador coast. In winter, in Britain, when everything is very cold, there may be a sudden change of weather, and mild humid air from the south-west may arrive and form fog. Incidentally, such warmer air, when it comes, will condense on the outside of our window panes and not on the inside (which happens when the room air is warmest), because condensation always occurs on the side which is exposed to the warmest air.

Another sort of fog is sometimes seen in conditions quite different from those already described. When a surface of water is at a much higher temperature than the air above it we may see little wisps of 'steaming fog' rising upwards. The air in contact with the water increases in humidity and is also warmed; as it rises, it immediately condenses in the colder air above. The same thing occurs when a bathroom becomes 'steamy'. It may sometimes be noticed over lakes or rivers, and is very obvious over a wooden fence heated by the sunshine after heavy rain.

The Times

FOG IN THE CITY OF LONDON



THE WHIRLING EARTH

WINDS are always an important feature of the atmosphere, since their presence or absence, force and frequency, often decides the climate of any particular place. In equatorial regions, where the power of the sun is greatest, there is a big uprising of heated air from the earth's surface. Cooler air flows in on either side to take its place, while the upward moving warm air spreads outwards at a higher level in the atmosphere and, moving in the opposite direction to the air at ground level, travels to the place where the wind at ground level began, before sinking once more to the earth's surface. In this way a circulation is set up, the descending air coming down at about latitude 30 degrees on either side of the equator. This descending air gets mixed with other descending air that has travelled from the north, and at the earth's surface some goes north and some goes south. We see from the diagram that another loop of circulation occurs, and air is found rising again about latitude 60 degrees. This time it is not due directly to heat, but to the meeting of warm air from the south with cold air from the north. Around the north pole, cold air is sinking and flowing away from the pole at the surface, while higher in the atmosphere the direction of the wind is towards the north, so this forms a third circulating system. The diagram shows what happens in the northern hemisphere; in the southern hemisphere exactly the same sequence occurs, but in the reverse order. The height of these air currents has been greatly exaggerated in the diagram. They occur in the region of the atmosphere which contains the clouds, and which is in reality a mere film round the surface of the earth. Owing to these circulating systems the wind at different levels is moving in different directions. Around the polar regions the upper movement is at no great height, and in Antarctica it has been noticed that, while the wind at the surface blew from the pole, above a height of 10,000 feet the wind was travelling towards the pole.

In studying the weather we are mainly concerned with the surface winds, and we have now to consider a complication which arises because the earth is not fixed, but rotates on its axis.

The speed of rotation at the equator is over 1,000 miles per hour, but nearer the poles it is much less. We do not directly feel this motion because everything around us is carried along with us; but the earth has not a perfect grip on the air, and the winds flowing north and south slither sideways as the earth rotates. Thus, the winds blowing in towards the equator get left behind because, starting from a higher latitude, they have a lower initial speed. On the other hand, winds blowing towards the poles are turned towards the direction of rotation. Since the actual movement of the earth's surface is less as we approach the poles, the winds overshoot. The resulting pattern of the winds is shown by the large arrows on the surface of the globe. But this is only diagrammatic: in reality, the distribution of the land and sea areas of the world quite alters the flow of the winds in many places, and the winds are also deflected by mountain ranges.

PREVAILING WINDS

WE may find in an atlas a chart of the wind systems in summer and winter, the direction of the winds being shown by arrows. These are the prevailing winds, that is, the winds that most often blow at any given place. Winds over land are not usually shown, as these are more variable; but over the oceans the winds are steadiest and strongest because there is less to impede them. They set up flowing currents on the surface of the ocean, like that of the Gulf Stream which starts out of the Gulf of Mexico and is blown up the north Atlantic by the wind. It may seem surprising that the wind can move the water so far, but if you blow hard over the surface of water in a bath you will see that the water begins to move too. There is a belt of stormy winds in the latitudes of 45° N. and 45° S. Because of the shape of the northern continents, these winds are mainly confined to the north Atlantic and the north Pacific; the belt in the southern hemisphere, however, is one of almost continuous storms with scarcely any land surface to impede them. These winds were called by sailors the Roaring Forties, and as they blow across the tip of South America, anyone going through the Straits of Magellan usually has a stormy passage.

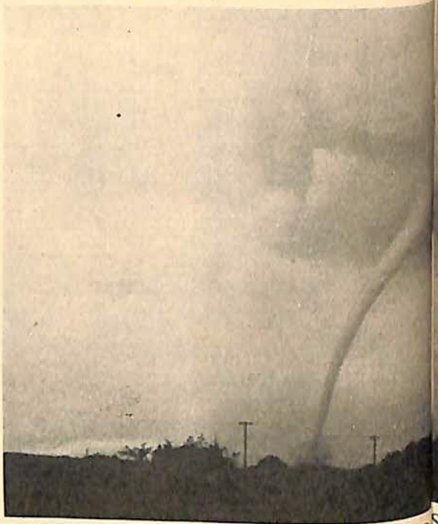
SPECIAL SORTS OF WINDS

THERE are hot winds, cold winds, gentle winds, and strong winds, and many are so clearly recognized that they have received special names. The strongest wind is called a hurricane. This was the form originally used in the West Indies, being derived from the Carib Indians' name for their god of storms, Hunraken. The same type of violent storm is known as a typhoon in the China seas, as a cyclone in the Indian Ocean, and as a Willy-Willy off the coast of north-west Australia. These storms may be hundreds of miles across, and the winds blow round in spiral fashion towards a centre, becoming ever more furious until they reach speeds of 100–200 miles per hour. At the very centre, called the 'eye' of the storm, the winds cease, or are much abated. Elsewhere, the lashing fury of the wind raises mountainous seas, dangerous for shipping; but regular weather forecasts enable ships to follow a course away from the storm. The hurricane requires large and continuous supplies of water vapour, such as are only found over warm seas; when it moves over a land area its strength weakens, and the winds die out.

One of the gentlest winds is the land or sea breeze. At seaside places the land surface becomes warm in the daytime, and the air above the land is warmed and rises; cooler air from over the sea then flows towards the land, and this is called a sea breeze. The opposite of this may occur at night: the sea is slowly warmed, and retains its heat, but the land surface cools rapidly, so there is a slight and less noticeable flow of air from land to sea. In eastern Asia the same effect on the grand scale causes the monsoons, of which the Indian monsoon is the best known. In winter, cold air flows off the continent towards the sea; in summer, when the land surface becomes much heated, the general direction of the winds is reversed, and humid air from the ocean brings the monsoon, or months of rain.

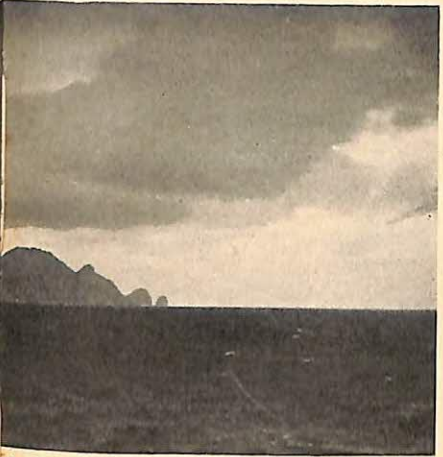
Of quite a different type are the downhill winds. One of these occurs locally, and generally at night, when cold air slides off hills and uplands and sinks into a valley, and goes on flowing downwards. Since cold air always tends to sink, it may flow like water, and so we get a wind, though it is not usually a strong one. Another downhill wind is that which started as an uphill wind, rising over mountains and shedding its water vapour as rain. As it descends on the far side of a mountain range, it is not only a dry wind but it increases in warmth as it descends. The explanation is quite simple. If

ENTRANCE TO THE STRAITS OF



A TORNADO, MANHATTAN, KANS

SANDSTORM SWEEPING OVER PO



AGELLAN, CAPE PILLAR *E.N.A.*

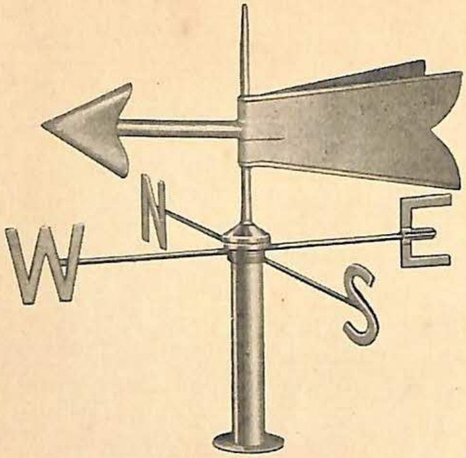
U.S. Weather Bureau: H. E. Dale

T SUDAN, AFRICA *E.N.A.*

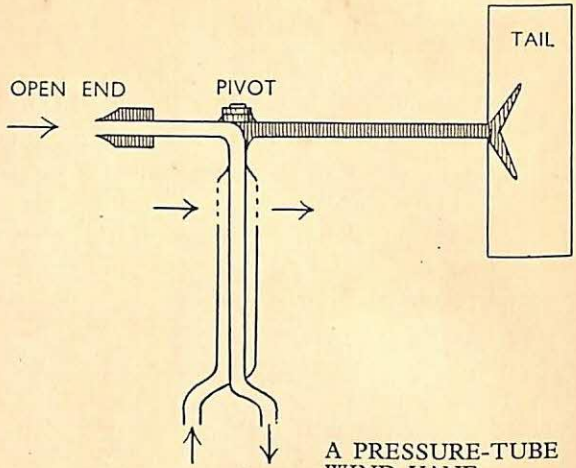
we let air out of a bicycle tire it will seem cool to the hand, because it is expanding; when we use a pump rapidly it will soon feel warm, because air that is compressed becomes warmer. Air that rises expands and becomes cooler; air that descends is more compressed, because air pressure is greater at lower levels, and so becomes warmer. This warm wind is called a föhn wind in the Alps, and a chinook in north America. The chinook descends on the east side of the Rocky Mountains and blows over the snow-covered plains in winter; as it melts the snow it gives good grazing for animals, which otherwise would have no food.

A very hot, dry, sand-laden wind called the sirocco blows off the great Sahara desert. Similar winds are known in other deserts, and when they are violent they whip up the sand into great clouds, causing a sandstorm. The most terrifying of all winds is the tornado, which occurs mostly in the United States east of the Rocky Mountains, and especially in the upper Mississippi and Missouri valleys. Although seldom more than a few hundred yards wide, its force is so terrific that it approaches with a frightful roar. One first sees an ominous sky with strangely coloured clouds milling round. A whirling column of water vapour like a gigantic elephant's trunk descends to the earth and tears up everything in its track. As its movement along is usually less than 30 miles per hour it is possible to get out of its way, but people generally go into cellars until it passes. In the long, wriggling trunk there is a partial vacuum, and the speed of the circulating wind, which is believed to be greater than any hurricane, causes enormous havoc. Whole houses are destroyed, and everything else is whirled upwards, chickens lose their feathers, people lose their clothes; men, horses, and even motor-cars have been carried aloft, sometimes without harm because the powerful upward currents prevent too sudden a fall.

A waterspout is rather like a tornado, but is not as a rule so violent, and it forms over the sea or a lake. Sometimes several are seen together. A descending trunk of whirling air comes downwards from the clouds until it touches the water, and some of the water is sucked a little way up the column. Tornadoes of considerable severity have sometimes occurred in England, and waterspouts are not very rare; which explains why things may be carried upwards, and why small frogs, fishes, and other creatures have sometimes descended from the sky. At Worcester, which is many miles from the sea, quantities of periwinkles rained down from the sky after a heavy thunderstorm in 1881.



WIND VANE
By courtesy, Negretti & Zambra



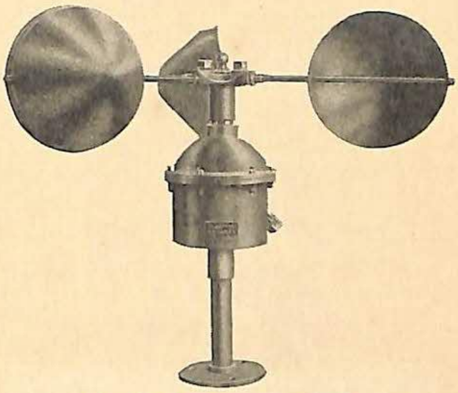
A PRESSURE-TUBE WIND VANE

MEASURING THE WIND

THE first thing we notice about a wind is its direction. A south wind is a wind that blows from the south, and a north wind blows from the north. The weather vane shows the direction from which the wind is blowing, and it is carefully balanced so that it will turn instantly even in the lightest breeze. It is still often called a weather-cock, because it was once usual to have the figure of a cockerel for the vane instead of the arrow that is customary nowadays. The points of the compass are shown by the letters below, which are held on fixed arms. These should be set so that the arm holding the N. points to the true north, not to the magnetic north. A wind which changes from SW. through W. to NW. is said to be veering. The motion of change, when seen on a compass dial, is in the same direction as the hands of a clock. When the motion is the opposite, as when a NW. wind changes to W. or SW., the wind is said to be backing.

To measure the speed of the wind is not always easy, because just as the direction is changeable, especially in gusty weather, so its speed is variable too. One method is to have three hollow metal cups revolving around a central pivot, as shown on the opposite page. The faster the wind, the faster they spin round, and this works an electric generator inside the base. From here, electric wires run to a dial or dials at a distance which record the speed of the wind in knots or miles per hour. Another method is to have a hollow tube as a wind vane, as shown at the top of this page. This is fixed on a high mast, 30 or 40 feet above the ground. The large tail ensures that the open end of the tube always points into the wind. The air blowing in is led downwards through the spindle and by the right-hand connecting piece to further tubing (not shown in the picture) leading to the ground level. The vertical central tube has an outer casing pierced with rows of little holes, and as the wind blows past these holes it causes a suction effect. This part is joined by the left-hand connecting piece to a second tube which also leads down to the ground. Here both tubes are attached to a recording instrument; and the difference of the air in the two tubes, one with a slight pressure and one with a slight suction, is made to indicate the velocity of the wind. Instruments which measure the wind are called anemometers. Sometimes the spindle of the weather vane is connected by a rod to the instrument, so that the direction of the wind may also be recorded.

The wind at higher levels is almost always stronger than that which we feel near the ground. This is because of the friction with the ground, and the irregularities of the surface, which slow up the wind. Except in stormy weather, we often notice that the wind tends to die down at sunset. A layer of cold air forms over the ground at night, and being relatively heavy it remains stagnant. Above it, at higher levels, the wind may continue to blow. In the morning the sun warms the earth again, the lower air becomes stirred and mixed with the higher, and after a few hours we may find that the wind has regained its strength at ground level.

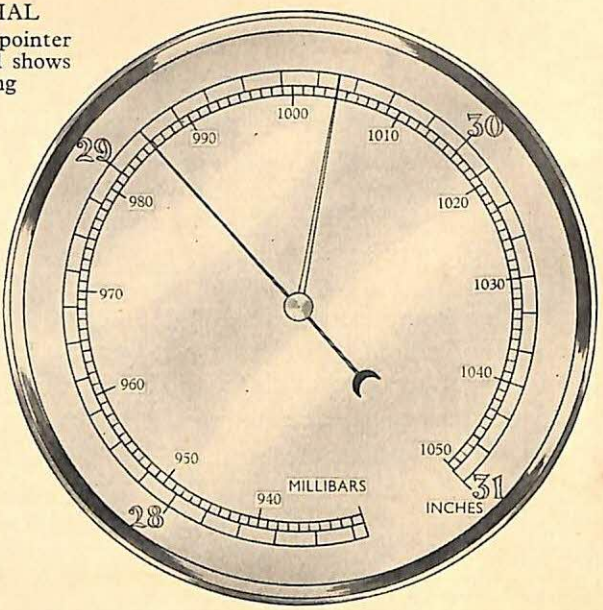


A CUP ANEMOMETER

By courtesy, Negretti & Zambra

In some years, winds of over 90 miles per hour occur at exposed places near the coasts of the British Isles, and the strongest gust of wind recorded was one of 113 m.p.h. in Pembrokeshire in January 1945. Any wind exceeding 38 m.p.h. is called a gale; winds over 50 m.p.h. are liable to bring down chimney pots, or uproot and overturn trees; and anything over 75 m.p.h. counts as a hurricane. All large buildings are made to withstand a certain strength of wind, but exceptional winds may be dangerous. It is recorded that a wind of 120 m.p.h. once caused the solid Empire State Building in New York to sway 4 inches. Large bridges, cranes, or other giant structures are often fitted with a wind alarm. This is a device like a fire alarm; it operates a warning bell or a horn and a red light goes on whenever the wind speed rises beyond a pre-determined velocity. A train about to cross an exposed viaduct, for instance, might have to wait until the wind moderated.

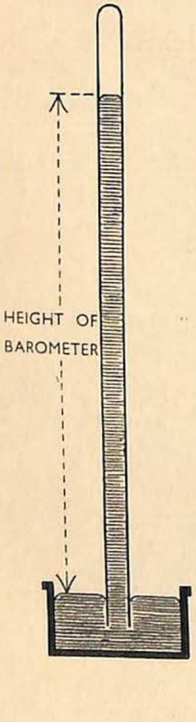
On the ocean, a hurricane causes tremendous seas, the tops of the waves being flung out in such sheets of spray that visibility is reduced to a few yards. On land, one of the greatest dangers is from flying debris; a wooden plank hurtling along in the air has been known to pierce right through a tree trunk. In severe hurricanes, winds of more than 150 m.p.h. are sustained for several minutes at a time, and occasional gusts of as much as 225 m.p.h. have been recorded.



A BAROMETER DIAL
The shorter or 'setting' pointer is turned by a knob, and shows the previous reading

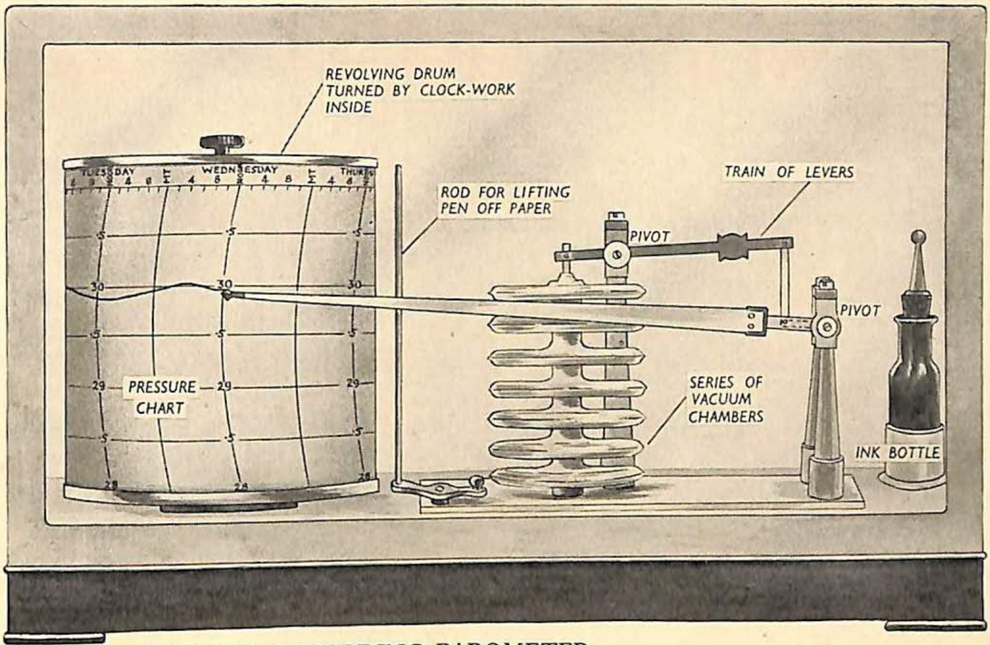
THE CHANGING PRESSURE

WE have seen that the higher we ascend the more the pressure of the atmosphere decreases. Pressure is measured by a barometer, which consists of a glass tube containing mercury. The tube is sealed at the top, and when filled with mercury its lower open end is immersed in a small cistern of mercury. The level instantly adjusts itself, a vacuum is created inside the tube at the top, and the 'height of the barometer' is the measurement in inches from the top of the mercury in the tube to the level in the cistern. The column of mercury is supported by the pressure of the air on the surface of the mercury in the cistern. If we ascend high in the atmosphere, the pressure becomes much less, and at about 18,000 feet the height of the barometer is only about half what it is at sea-level.



A more handy form of barometer, convenient for taking up to heights, is called an aneroid. The mechanism of this instrument consists of a small vacuum chamber with a spring inside, sensitive to changes of air pressure, and a system of levers connected to a pointer on a dial. It may be adapted to serve as an altimeter for aeroplanes merely by marking the dial with a scale showing the height in feet above sea-level which corresponds to the changing pressure. But to get a correct reading we must first know what the pressure is at sea-level, and unfortunately this varies and must be allowed for each time the altimeter is used. So really the barometer measures two things: the height above sea-level, and also the fluctuations due to the changing distribution of air pressure; and whichever reading we are taking, we have to make allowance for the other.

Since late in the seventeenth century it has been customary to mark the dial of a barometer not only with the height of the mercury in inches, 28, 29, 30, 31, but also with the words 'Rain', 'Change', and 'Fair'. This was because it had been discovered that the higher pressure generally indi-

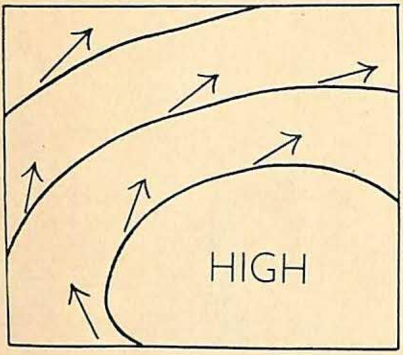

REVOLVING DRUM TURNED BY CLOCK-WORK INSIDE
TUESDAY
WEDNESDAY
THURS
ROD FOR LIFTING PEN OFF PAPER
TRAIN OF LEVERS
PIVOT
PIVOT
30
29
28
PRESSURE CHART
SERIES OF VACUUM CHAMBERS
INK BOTTLE

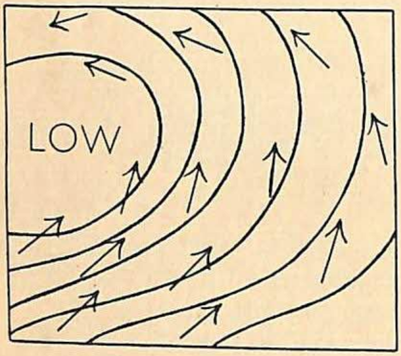
THE BAROGRAPH, OR RECORDING BAROMETER

cated fine weather. In practice it is not so much the particular reading that matters, but whether, as the hours pass, the movement of the barometer shows a rise or fall. In estimating probable changes in the weather, several others things also have to be taken into account. Both the aneroid and the older and more accurate type of barometer are nowadays marked with a scale of millibars, as well as inches. The millibar is a unit of pressure, and is more suitable for scientific records. The figures 'mb.' that appear on weather maps show the height of the barometer in millibars, and we may take 1,012 mb. as approximately the normal reading at sea-level.

The barograph, illustrated above, is an aneroid barometer which makes a continuous record of the changing pressure. Instead of having a dial, the pointer is arranged as a pen, and marks a line on squared paper like a graph. The paper is fastened round a drum driven by clockwork, and each strip of paper lasts a week. The part which has a set of watch-shaped vacuum chambers arranged like a bellows is sensitive to changes in pressure, and is connected by levers to the pen. The vertical rod near the drum lifts the pen off the paper, when the paper is being changed.

It is easy to understand why the pressure of the atmosphere at the surface of the earth is variable. We have seen how, in the tropics, a great amount of warm air is rising, and how cooled air is descending in latitudes 30° N. and 30° S. The pressure of air at the surface is reduced where air is rising, and increased where air is descending; or we may say that the reduced pressure causes the surface winds to blow in towards the equator—we are really describing the same thing, the circulating wind system. The trade winds blowing in towards the equator are very steady, and the areas of low pressure and high pressure are relatively stable, except that they vary in latitude according to the season. It is quite otherwise in latitudes from 40 to 60 degrees. Here much smaller patches of high and low pressure intermingle in an ever-changing pattern, and the weather, as a consequence, is much more variable.



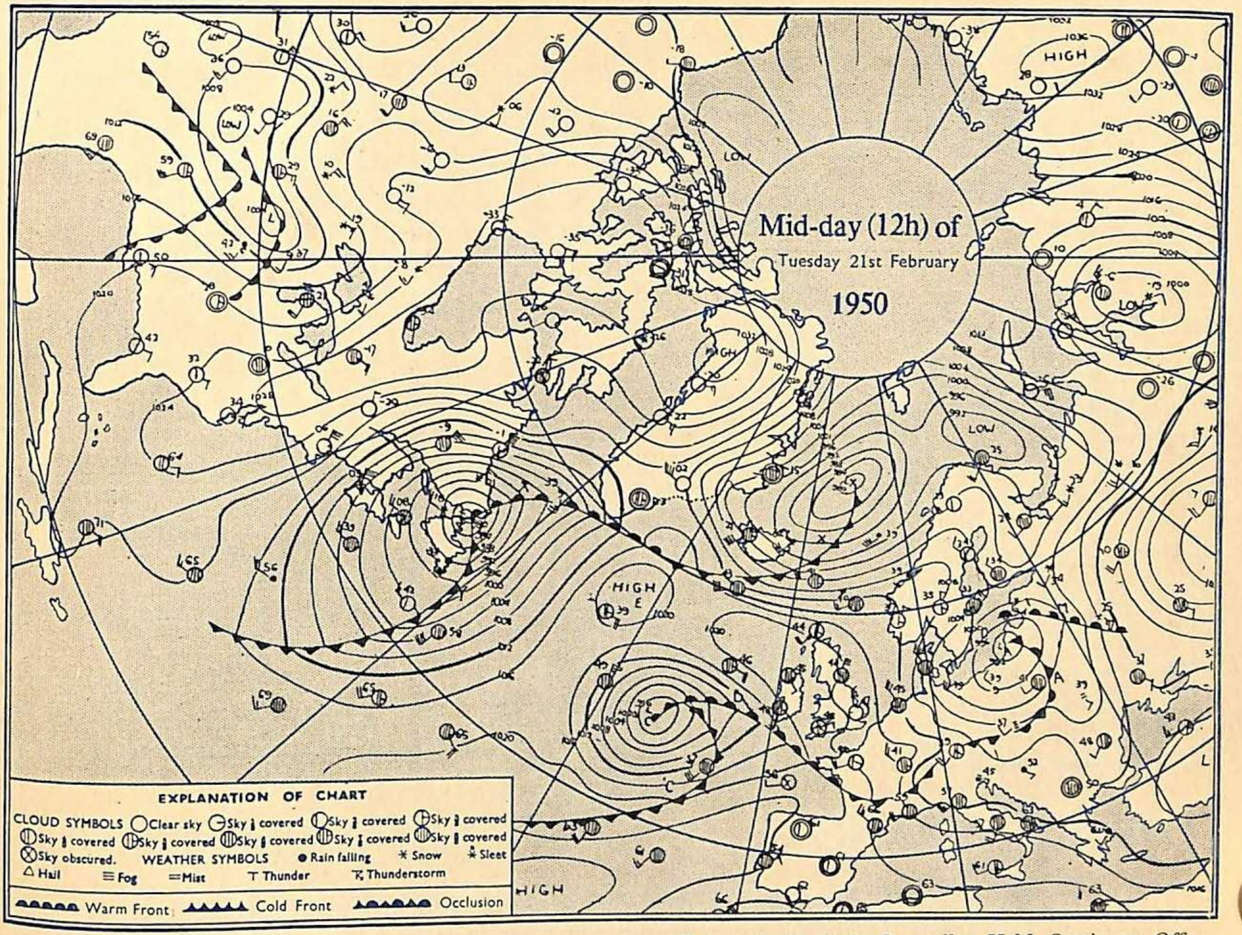


All weather maps show the distribution of air pressure. Barometer readings, at a given time, are taken from a number of different places. As these places may be at varying heights above sea-level, the readings are adjusted mathematically to sea-level equivalents. They are then plotted on a map, and curved lines, called isobars, are drawn to run through all places which have approximately the same pressure. We then see at once where there is an area of high or low pressure. Where the isobars are far apart, the pressure changes are gradual; where they crowd close together, the pressure decreases rapidly, and this means that the winds will be strong. Wind direction is shown by arrows, and it will be seen that surface winds do not blow straight out from a high nor straight in to a low-pressure area. They are deflected by the rotation of the earth, and tend to run more nearly along the isobars. We are now seeing a different sort of air circulation, not that between different levels of the atmosphere, but that of the atmosphere at the surface of the earth. Throughout the northern hemisphere, air circulates in a clockwise direction around areas of high pressure, and anti-clockwise around areas of low; in the southern hemisphere it is the opposite in each case.

THE WEATHER MAP

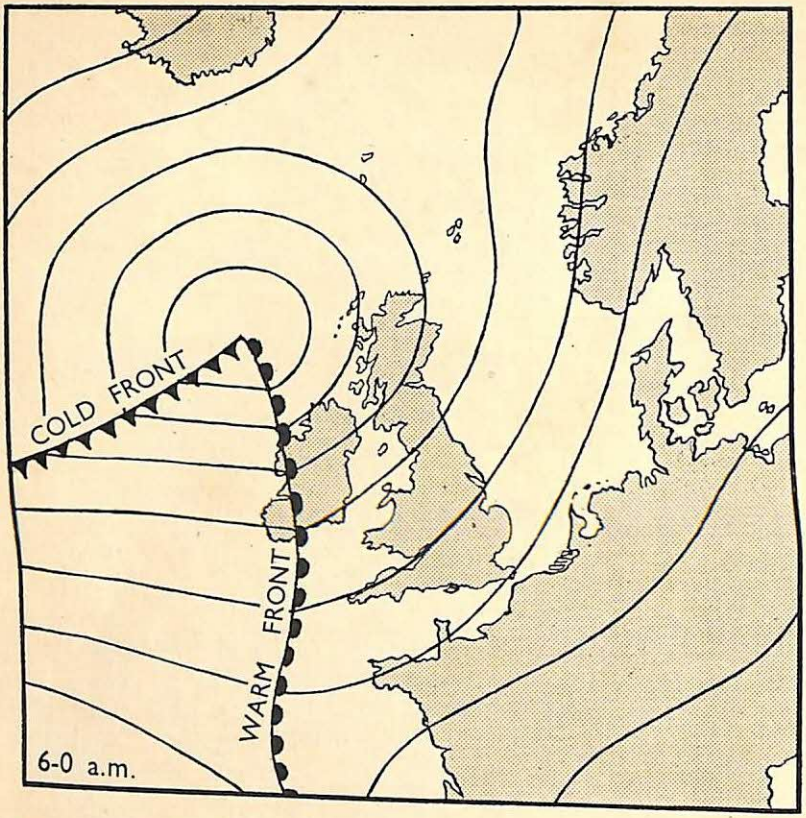
IN Britain, maps showing the state of the weather every six hours appear in the *Daily Weather Report* published by the Meteorological Office. Maps in newspapers are usually forecast maps, showing what the weather is expected to be; but the official maps show the existing state of the weather at a particular hour, and are not in themselves forecasts, although a written forecast is published with them. Air flows over land and sea, so the isobars on the weather map cross the land and sea too. Some encircle high pressure areas and some encircle low pressure areas. The heavy toothed lines on the map indicate belts of rain, which are explained on the next pages. The map only shows the state of the atmosphere near the surface of the earth at a particular time and date. The areas of high and low pressure are in continual change and movement. No two maps are ever quite alike.

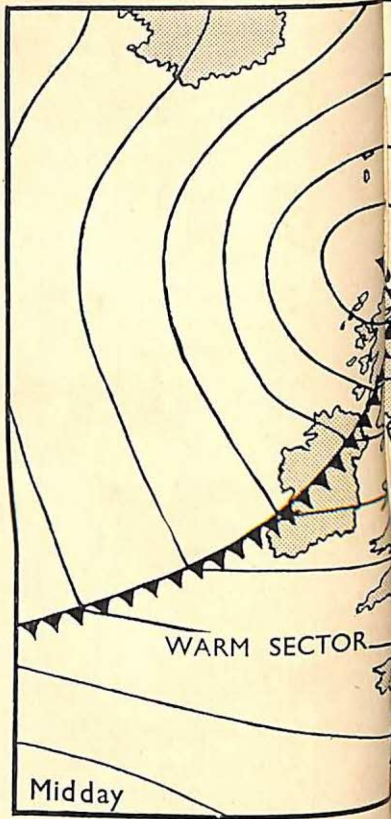
Each place that reports the state of the weather is called an observing station, or simply a 'station', and its position on the map is marked by a circle. It transmits by telegraph or radio a full report of the existing weather every six hours, in a special code. Circles which appear on the sea are ships which transmit code messages in the same way, giving also their position at the time. Special 'weather ships' are also sent out to report from those parts of the ocean where ships do not normally go. The information from all the stations is received by the central fore-


Mid-day (12h) of
Tuesday 21st February
1950
HIGH
LOW
EXPLANATION OF CHART
CLOUD SYMBOLS ○ Clear sky ⊖ Sky 1/8 covered Sky 2/8 covered Sky 3/8 covered Sky 4/8 covered Sky 5/8 covered Sky 6/8 covered Sky 7/8 covered Sky 8/8 covered ⊗ Sky obscured.
WEATHER SYMBOLS ● Rain falling * Snow Sleet △ Hail ≡ Fog = Mist T Thunder Thunderstorm
Warm Front
Cold Front
Occlusion

By permission of the Controller, H.M. Stationery Office

casting station at Dunstable in Bedfordshire, and is plotted on a large map, called a synoptic chart, by means of many special symbols. The published maps are a simplified version, in which only a few symbols appear. At each station is an arrow showing the direction of the wind; except that where the arrow-head ought to be is the circle of the station itself. (Note that this arrow points the same way as the wind, whereas the wind vane points into the wind.) The length and number of feathers to the tail indicate the strength of the wind; from a single short feather for a very light wind, to five long feathers for a gale. If the sky is clear the circle of the station is left white; if clouded the extent is shown by the amount of shading within the circle. An extra circle, outside the ordinary circle, indicates a calm—when there is no wind at all. Rain is shown by a black dot, drizzle by a comma; and on more detailed maps various other symbols may be used. The figures next to each station show the temperature in degrees Fahrenheit, and the figures on the isobars are the barometer readings in millibars; the 1,012 isobar is shown thicker than the others. These symbols are the principal features of a weather map, and once we follow their meaning it is not difficult to understand the facts which any weather map gives.

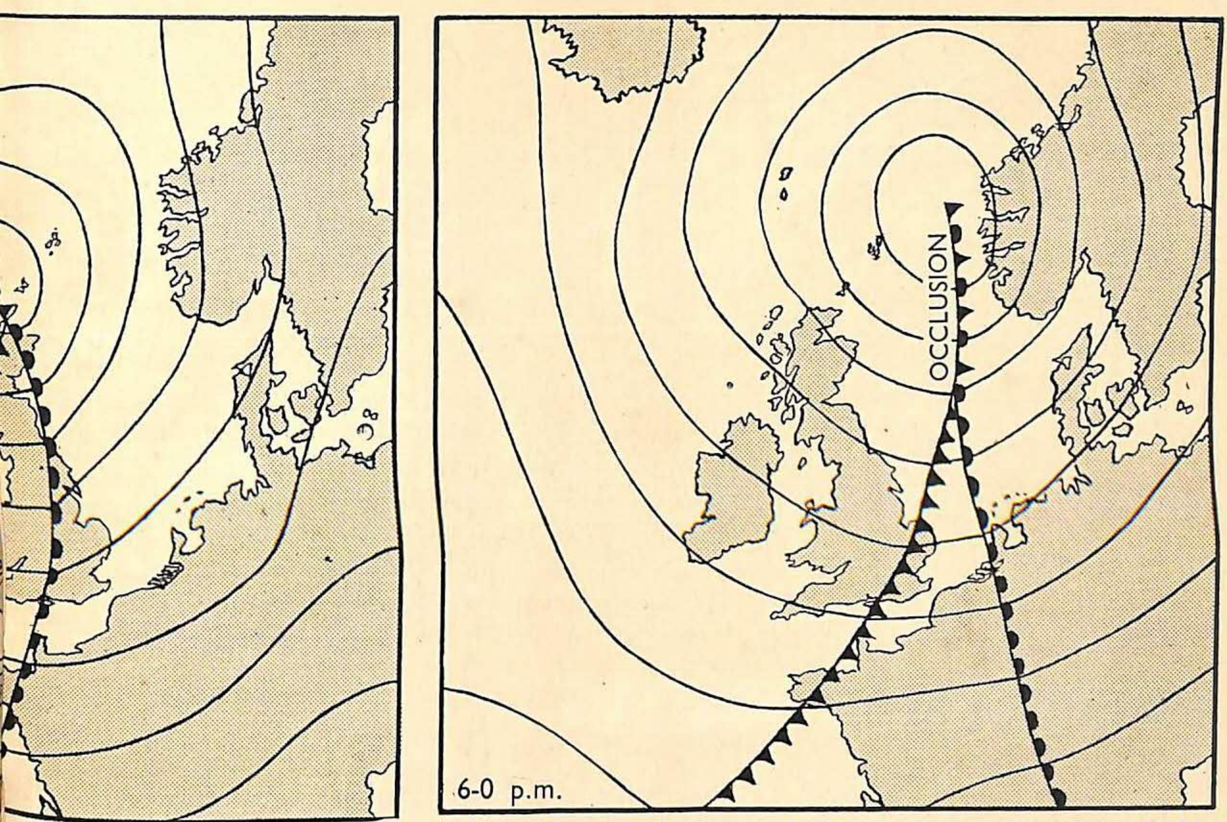




DEPRESSIONS

AN area of low pressure is called a depression, a disturbance, or merely a 'low'; and such depressions give temperate latitudes their variable weather. Formerly the word cyclone was used to describe a depression, and the type of weather it brings is still called cyclonic. The similarity is that the winds blow round a centre of low pressure. But in a true hurricane or cyclone, the eye or centre of the storm may have a pressure as low as 28¼ inches (957 mb.) whereas in ordinary depressions the pressure at the centre is not usually much less than 29¼ inches (990 mb.). In the British Isles the sequence of depressions which bring rain is a prominent feature of the weather. Depressions also move across the United States, but as a rule they alternate with high-pressure areas; in Britain depressions may follow one upon another for weeks at a time.

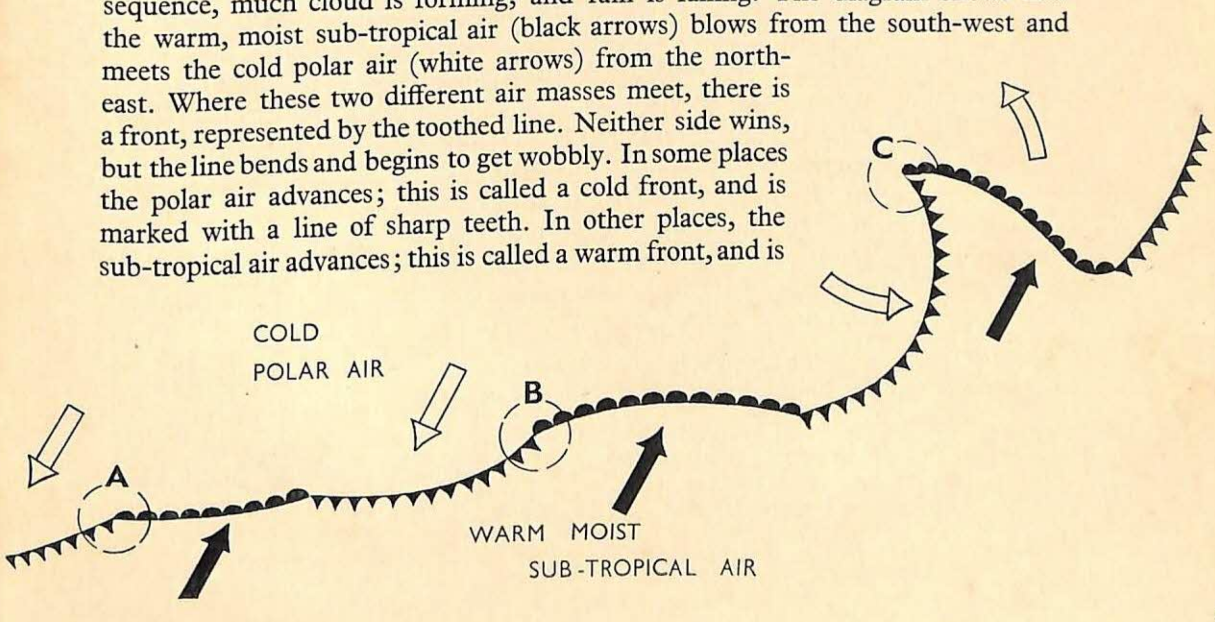
In a depression there are two movements to consider: the winds, which represent the circulating air, and the movement of the whole system itself. In a deep depression, that is, one with very low pressure at the centre, winds may circulate with gale force. Normally, however, we do not expect winds of much over 30 miles per hour. The movement of the whole system is liable to be erratic both in direction and speed. In the British Isles depressions mostly approach from the west or south-west, and move off east or north-east. Normally their speed averages that of a bus or train, but as the rate is sustained day and night we must expect to find a depression in quite different positions on the map on successive days.

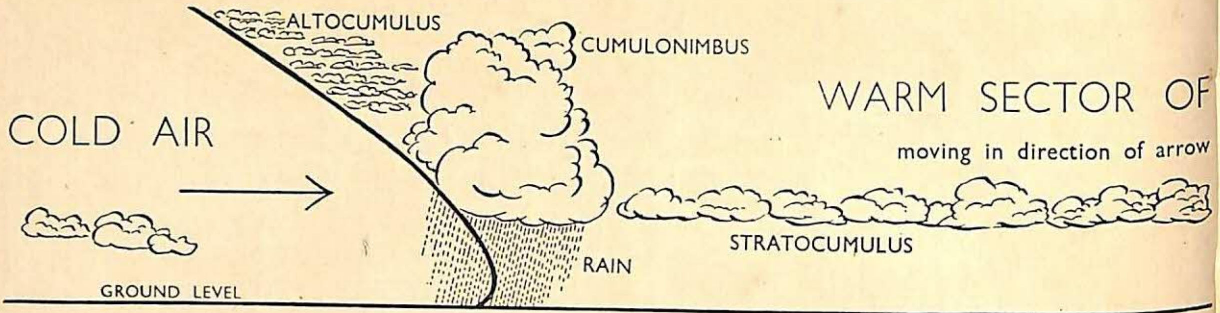


THESE MAPS SHOW A DEPRESSION MOVING OVER THE BRITISH ISLES

THE RAIN BELTS

WHEN we look at the isobars on the map we see at a glance the distribution of pressure. Rain does not occur all over the low-pressure areas, but mainly along certain belts called 'fronts'. The origin of these is simple. They represent the line where different air masses meet, and where, as a consequence, much cloud is forming, and rain is falling. The diagram shows how the warm, moist sub-tropical air (black arrows) blows from the south-west and meets the cold polar air (white arrows) from the north-east. Where these two different air masses meet, there is a front, represented by the toothed line. Neither side wins, but the line bends and begins to get wobbly. In some places the polar air advances; this is called a cold front, and is marked with a line of sharp teeth. In other places, the sub-tropical air advances; this is called a warm front, and is



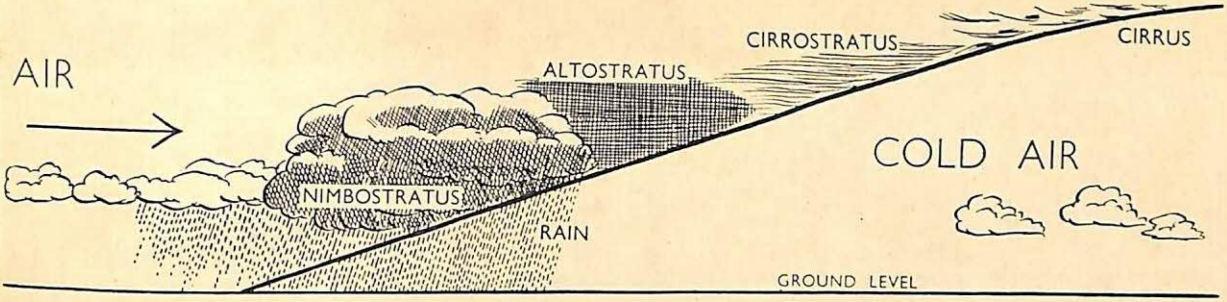


marked with rounded teeth. Notice how the whole line of the fronts develops a sort of wave. At first, around the centre *A*, where a depression is beginning to develop, this may not be very obvious. At *B*, something more definite is happening, while at *C* a depression is fully developed. There is a warm front and a cold front, and the winds have formed a circulating movement. Each depression has its fronts, not necessarily connected with other depressions; and wherever there is a warm front or a cold front, we may expect a belt of rain.

A DEPRESSION ARRIVES

OFTEN the first visible sign of an approaching depression is a change in cirrus cloud from being mere wisps or patches of open thread-like structure to a more solid sheet of cirrostratus. The direction from which the cirrostratus appears to spread shows us the direction from which the warm front may be expected, bringing rain. This change in the cloud may be as much as 500 miles in advance of the front itself, so we may have ample warning. As the hours pass, the barometer reading will become progressively lower, indicating a steady fall in pressure. The high cloud thickens to altostratus at a lower altitude of some 12,000 feet, giving the sun a watery look. Finally, the cloud develops into a very thick layer of nimbostratus, the dull shapeless rain cloud, and rain falls steadily over a wide area. If there is already much cumulus cloud at a low level, we may not see the oncoming changes in the higher clouds.

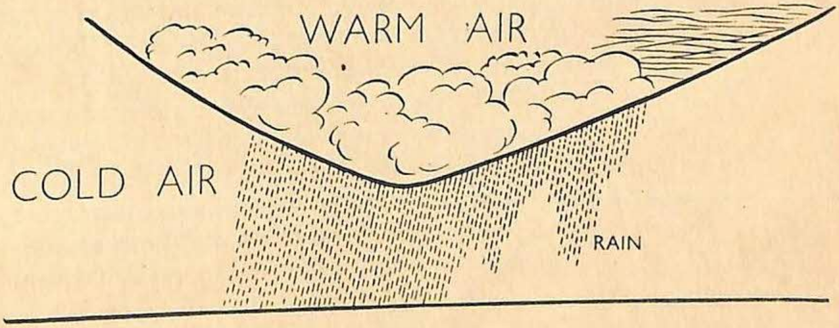
Though the warm and cold fronts are marked by a line on the maps, this does not mean that the line is sharply defined like a vertical wall. When the warm front advances it slides up over the cold air, and this causes the sequence of cloud formation just described; a sequence which will be more obvious in the sectional diagram above. At first, for some distance behind the warm front, there will be a warm sector of air. Here, after the rain, the sky may be largely overcast with stratocumulus cloud. The area of this sector may be large; but sooner or later the cold front arrives. The cold air, being the heavier, undercuts the warm air sector as it advances. The warm air is thrown upwards steeply, making a high bank of cloud several thousands of feet thick. This may develop into cumulonimbus, giving heavy rain or hail and thunder. The special feature of the cold front



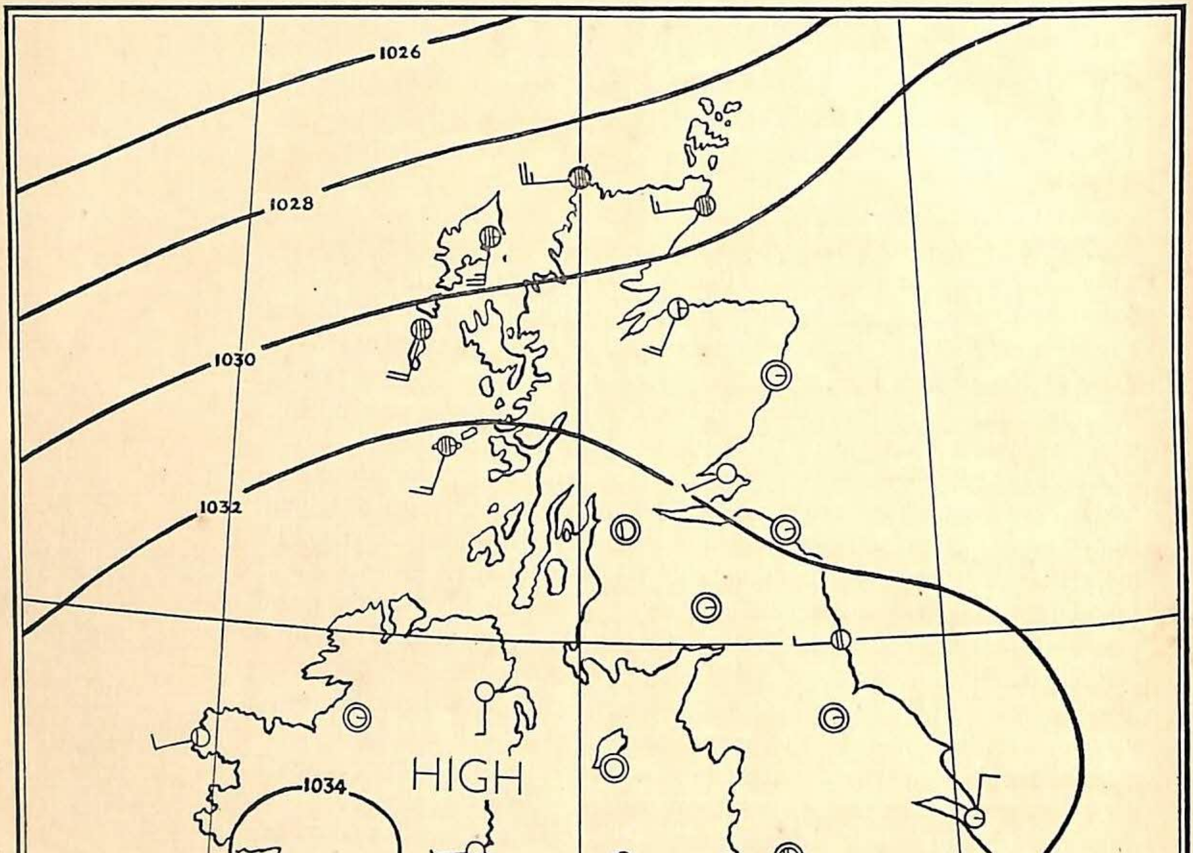
is its narrowness compared with that of the warm front. Though in total length it may extend hundreds of miles, the width may sometimes be only a few miles, and generally not much more than about 40 or 50 miles.

As the front is in movement, it does not take long to pass our place of observation. Cold, squally showers occur; and then quite suddenly the sky clears, the temperature falls, often perceptibly, and the wind veers sharply, so that if formerly from the west it may become north-westerly, and the barometer begins to rise. The drop in temperature is usually slight, but occasionally it may be as much as 10° or 15° F. 'Hasn't it turned cold?' people say, as they meet each other. The air which has arrived is the cold polar air; the sky is generally an intense blue, and visibility becomes good. Soon, in the bright sunshine, heated air rising from the ground starts the formation of cumulus cloud.

The previous pages show a depression moving over the British Isles; the direction of the isobars in the warm sector shows the direction in which the depression as a whole is travelling. As the cold front moves forward it catches up with the warm front, the warm sector growing ever narrower. Beginning from the centre of the depression, the cold front overtakes the warm front. This is called an occlusion. It means that the warm air is lifted right off the ground; the rain subsequently becomes less heavy, and all the clouds that have formed may continue to drift about for some days. Since most depressions become fully developed while over the Atlantic, the majority do have occluded fronts when they arrive over Britain. In fact they rarely arrive in any regular manner; and as they jostle with each other, in different stages of growth, it makes the maps look very complicated; especially if, in unsettled weather, old occluded fronts are still drifting about in an erratic way.



AN OCCLUSION: *the warm sector is lifted off the ground*



From an official map, by permission of the Controller, H.M. Stationery Office

THE ANTICYCLONE

THE map opposite shows an area of high pressure, commonly called an anticylone because it is the exact opposite of a depression or low-pressure system. The isobars are generally found farther apart, because the differences in pressure are gradual. Winds are light and variable, and tend to circulate in a clockwise direction. In an area of high pressure, as already explained, air is descending towards the surface of the earth, and in descending it becomes warmer, because it is more compressed; and being warmer it is also relatively drier, so there is not usually any rain. Notice on the map how many stations in the centre have no arrow, but show an outer circle instead, indicating a calm; that is, no wind. Round the outer edge of the anticyclone, wind is often more noticeable, and usually blows steadily.

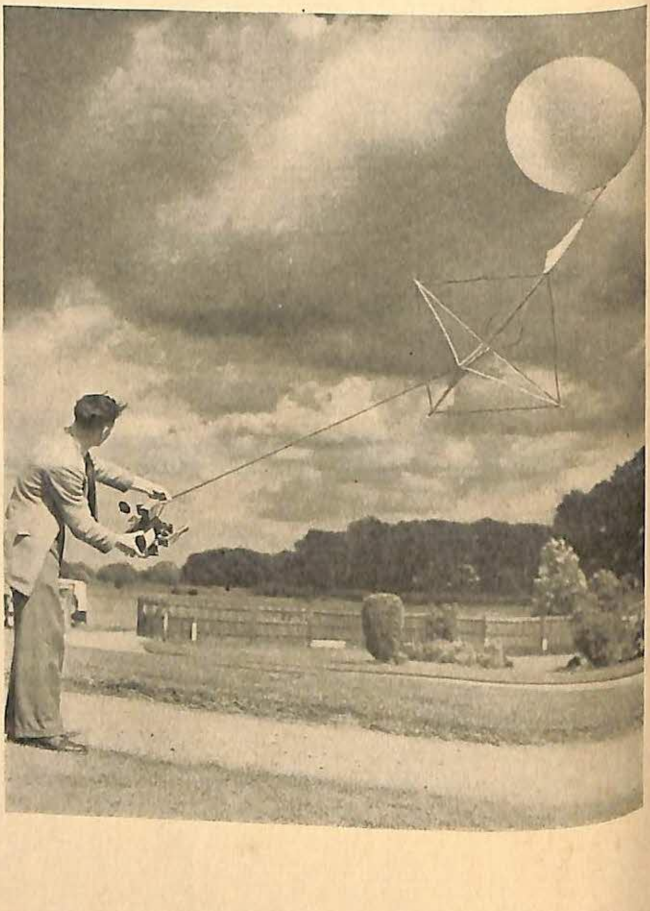
A marked feature of the anticyclone is that, as a system, it tends to persist for some time, and is also slow-moving. A vigorous depression may come along, but has to skirt round the edge, perhaps only making a dent in the area of high pressure, which gives a little at one part, only to expand somewhere else. The anticyclone may thus last not only for days but for weeks. In winter we may have clear skies and frosts; but owing to the chilling of the earth's surface, and consequent inversion of the usual lapse-rate of temperature, we may instead have widespread fog; or there may be a persistent layer of relatively low stratocumulus cloud, giving dull skies, but without rain. In summer, anticyclones in Britain are apt to spread from the adjacent warm continent, or they may be extensions, or parts detached from the permanent sub-tropical high pressure area of the Azores. The whole air mass is therefore warm to start with, and with further continuous sunshine we usually get heat. Temperatures exceeding 90° F. are generally rare in the British Isles. The highest on record was 100·5° F. at Tonbridge, Kent, in 1868; and 100° F. was registered at the Royal Observatory, Greenwich, in 1911.

THE WEATHER FORECAST

A CAREFUL observer, noting changes in the wind, temperature, and barometer readings, and watching for any new development in the clouds that may be visible, will have a good idea as to what the weather in the next few hours is likely to be. Some types of weather in the British Isles persist for a week or more at a time, so if the observer is experienced, he may sometimes make his own forecast for a day or more ahead. But if a depression over the Atlantic is approaching, he may have no foreknowledge whatever until the change is almost upon him. The official forecaster, on the other hand, has not only his own view of the sky and the instrument readings of his own station: he has also the reports coming in from afar, from a whole network of stations marked on the map, so his range of observation is enormously extended. With the latest maps in front of him, he is able to view the whole sequence of past weather and the probable trend of the immediate future, and he also has the advantage of the very latest reports coming in.

He may notice, for example, that a depression is moving in a certain direction, and at a certain speed; and so it will be possible to say at what times the warm and cold fronts will be expected to reach different parts of the country. Even then the forecast sometimes proves wrong. In most cases this is because some development has been delayed, or has come earlier than expected. The sequence of weather, rain, showers, and sunshine, may even be the same at any given place, but the times of occurrence may be entirely different from what was first forecast. In Britain, where the weather is notorious for its changeability, it is not always possible to be certain of a forecast for a whole day ahead, but it is usually possible to obtain an accurate forecast for a few hours ahead for any district. One of the difficulties of making a general forecast for the whole country is that the day's weather is often too complicated to be summed up in a few sentences. It may be frosty in Kent while it is raining in Cornwall, so obviously we have to divide the country into areas if the weather is to be correctly forecast.

The air is in constant motion, so it is hardly surprising that the movements of depressions, as they appear on the map, are as unpredictable as the swirls and eddies we see on the surface of a river. If we could see the deeper currents



RELEASING
THE RADIO-SONDE

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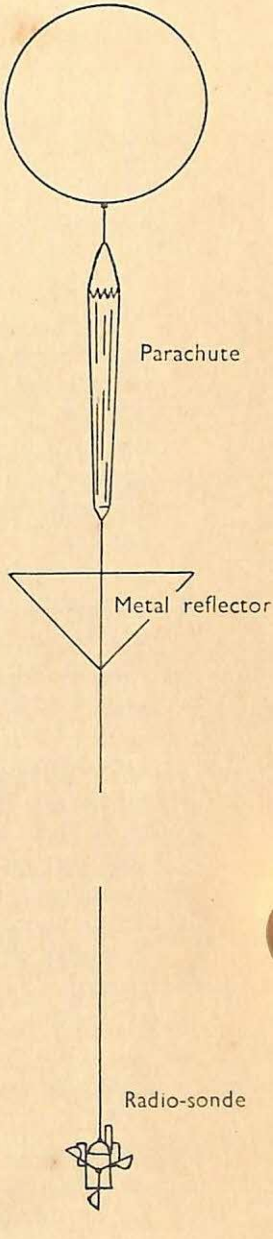
of a river, we might find some explanation of the surface movements; and it is the same, only the other way on, in the case of the atmosphere. The ordinary weather maps show what is happening at the surface of the earth. If we knew also what is happening in the upper levels of the air, we might have the explanation of what is occurring at the surface.

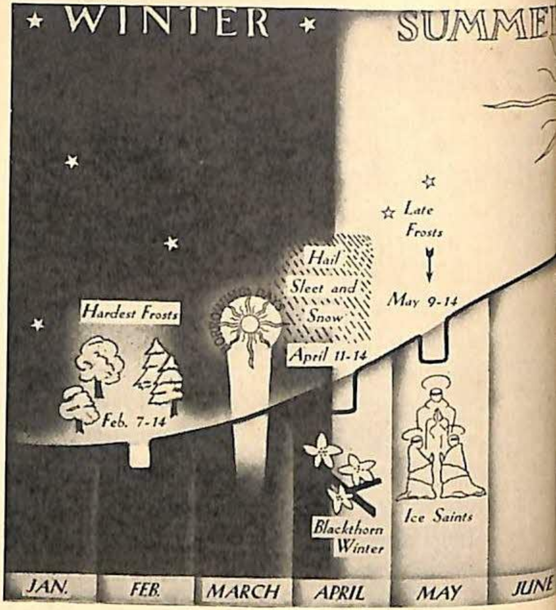
This information is now obtained by sending up small hydrogen-filled balloons which carry instruments known as Radio-sondes. The balloon is fastened to a parachute, which carries a triangular framework of aluminium below which is suspended the Radio-sonde itself. As the balloon ascends, it is tracked by radar signals from the ground, which are reflected by the aluminium frame. In this way it can be followed even when hidden by the clouds, and its position at different times gives the wind speed at various altitudes. The ascent sets in motion three hollow cups on the side of the instrument, which rotate windmill-fashion, and so set going the mechanism which transmits continuous radio signals to the ground, giving the changing humidity, pressure, and temperature of the air at different altitudes. When the balloon reaches a maximum height it bursts; the parachute then opens out and sails gently downwards with its load. As its windmill arms continue revolving, the Radio-sonde continues to transmit signals until it falls to earth. So many of these instruments are used that they are mass-produced. About half are recovered after use, and there is a small reward for finding and returning one.



HOW TO OBTAIN A FORECAST

EVERYONE is concerned with some aspect of the weather: the air pilot will look for the fronts; the motor-driver will want to know if there will be a frost or a fog; seamen, if there will be a gale; the farmer may want sunshine, or he may want rain. People who want an accurate forecast for a few hours ahead for any particular district have only to telephone the nearest branch of the Meteorological Office, and the information is supplied free.

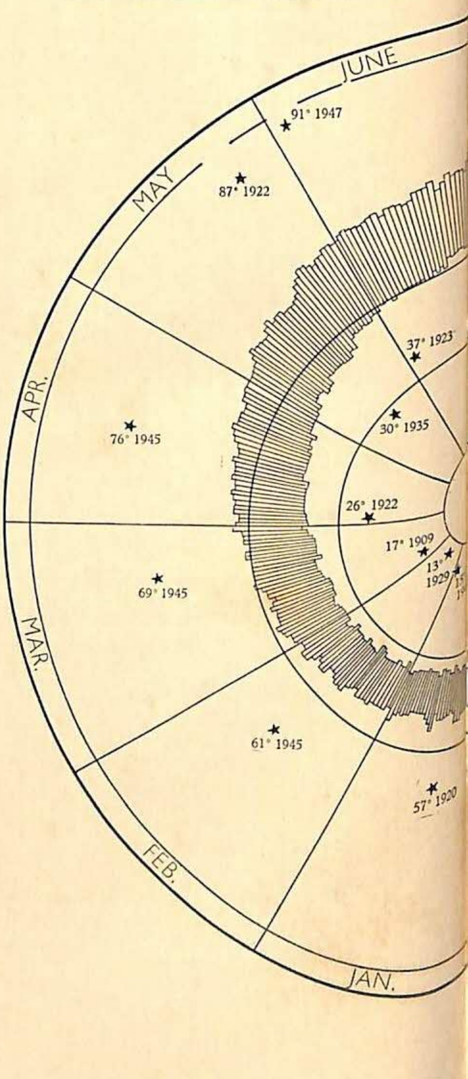
BRITISH WEATHER

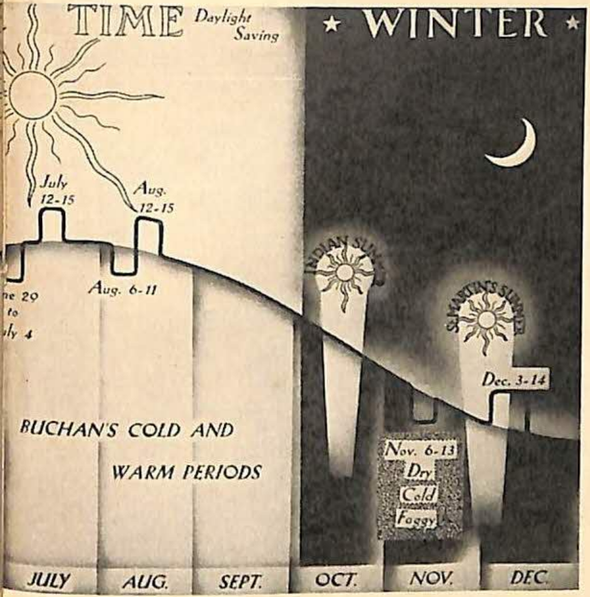


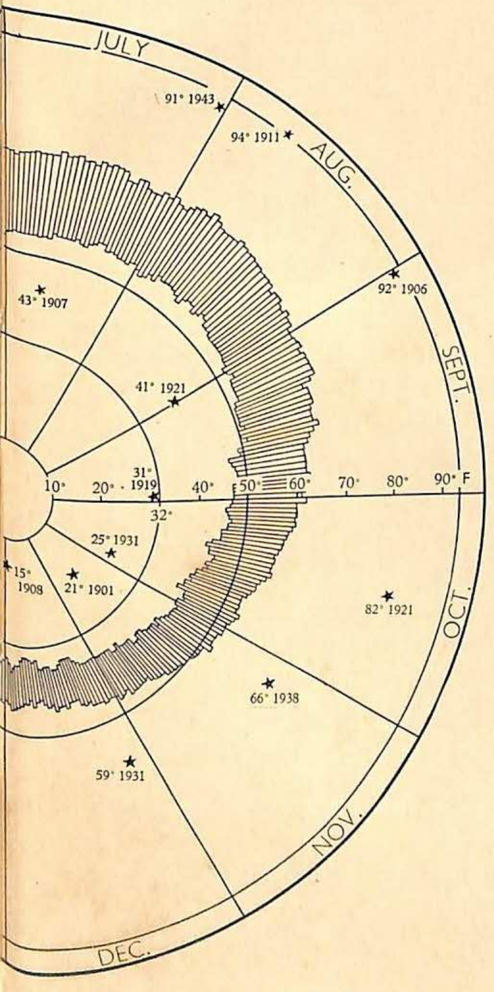
IN Britain the weather is a never-failing topic of interest. It changes from day to day and from hour to hour, and its changes are often capricious and exasperating. But we are spared the unbearable extremes of heat and cold which occur in some countries; it was Charles II who said there was no day in the year when an Englishman could not enjoy some outdoor exercise. The changing weather of Britain has confounded the plans of every would-be invader since William the Conqueror, and even he was nearly lost when the wind and tide separated him from his fleet.

The British Isles lie in a relatively high latitude, as high as Kamchatka and much nearer the pole than Quebec or Tokyo. What makes the climate mild is the fact that the winds called the Westerlies bring air from the sub-tropics; and the Gulf Stream, spreading out as the North Atlantic Drift, carries a relatively warm sea current towards the western and northern coasts of Britain. The most frequent type of weather is that derived from this south-westerly air stream, and the series of depressions associated with it. Even in winter, over half the weather we get is of this sort, which explains why some winter months, though wet and stormy, are apt to be relatively mild. In summer, anticyclones may spread over the country, bringing with them warm air, in the way already described. In fact, the origin of the air decides the temperature; if cold polar air covers the country, no amount of sunshine will ever produce a really hot day. Sometimes the air flowing over Britain comes from a north-easterly direction and we get cold, dry, biting winds, which may be persistent day and night for days and even weeks together. This most often happens in the spring months, when there may be also much sunshine. Occasionally in winter, intensely cold dry air from the continent or from Russia may spread over Britain. When this happens, a prolonged spell of severe weather is the result.

In spite of the fact that British weather is so changeable, it is possible to notice certain characteristics



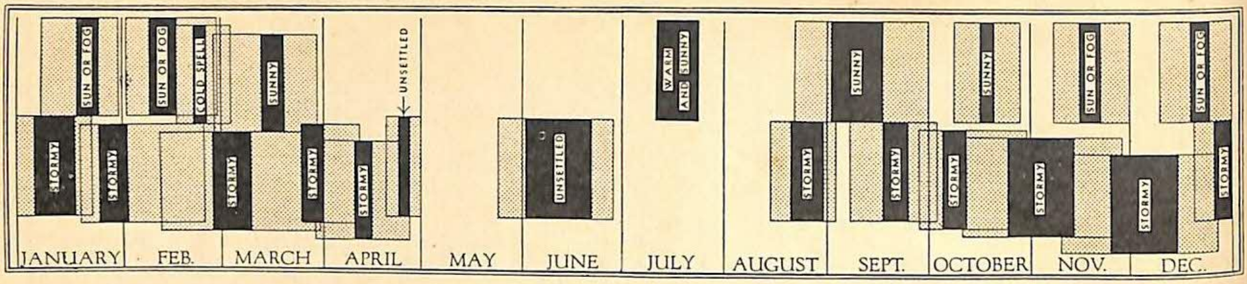




which repeat themselves. There is the rhythm of the seasons, and there is a tendency for certain sorts of weather to reappear at certain times. The first diagram shows the rise and fall of mean temperature during the course of the year. It will be noticed that the lowest temperatures generally come in February, and the highest in July, as the earth changes temperature slowly and lags behind the seasonal position of the sun. The steps up or down, added to the graph, mark diagrammatically the warm or cold periods noticed in Scotland by Dr. Buchan in the nineteenth century. Some of these often recur throughout Britain about the expected times; such as the cold period in the middle of April, and the saints' days in early May that are called the Ice Saints because they often bring frost. Certain other traditions of weather lore are here included. The 'Borrowing Days' are the calm sunny days of March that seem to be borrowed from mid-April. St. Luke's Summer is the name given to the fine October days that have sunshine; and St. Martin's is a similar but shorter period sometimes appearing in November.

The circular diagram shows the average or mean values of the highest temperatures and the lowest temperatures for every day in the year as recorded at Kew Observatory. They are the averages for a period of years, 1871 to 1940, and a similar record of any particular year would look more erratic, though still conforming to seasonal changes throughout the year. The minimum temperature usually occurs at night, and we see that the difference between the maximum day and minimum night temperature is greatest in spring and summer, and nights in spring are colder than nights in autumn. When the temperature is below 50° F. it is cold enough for a coat; but much depends on the wind, as a calm cold day is much more bearable than a windy day of the same temperature. Besides the mean values for every day, the record temperatures for every month also appear in the diagram. These are the highest and lowest temperatures that have been recorded in the period 1901 to 1947.

An up-to-date study of the weather over a period of fifty-two years has now been made by Dr. C. E. P. Brooks;



this is summarized by the sequence of the months in the diagram above. The lower row of rectangles mark wet or stormy periods. The upper row mark periods of anticyclones, which in summer bring calm warm days and in winter calm sunny days, or fog, or overcast skies, but no rain. The solid black illustrates the average position of each period, the shading on either side indicating that it may sometimes begin earlier or end later. The consequent overlapping makes recognition more difficult, but in spite of this, certain facts stand out. There is a tendency for anticyclones to appear in the middle of the months of winter and in July and September. Storms, on the other hand, mostly occur at the beginning or end of months. The end of August and the end of December, for instance, are often stormy. But we have to remember that the diagram is not a forecast: these are averages, and therefore show us what we may most probably expect in any given month.

OTHER CLIMATES

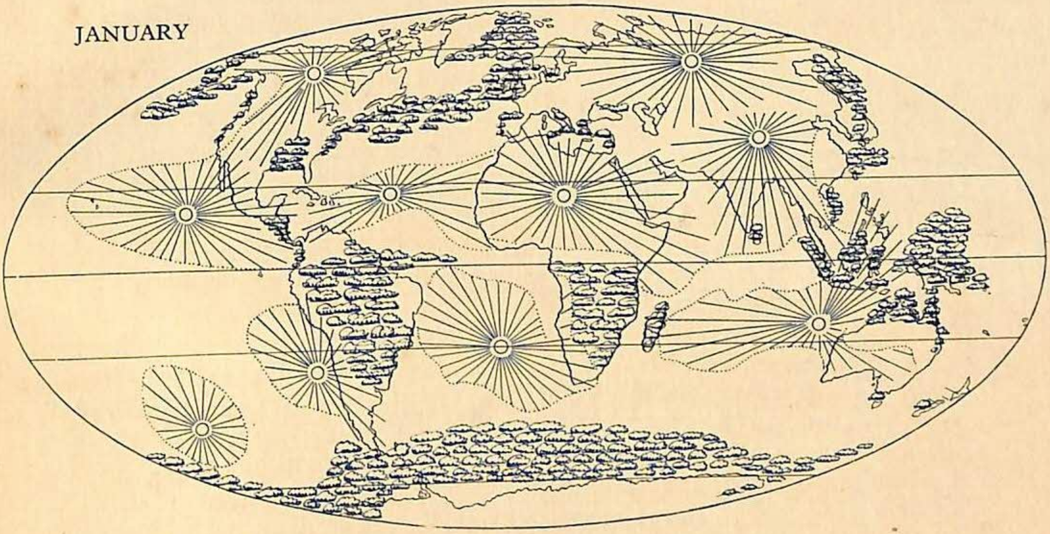
UNLIKE temperate latitudes, where the weather is very changeable, many parts of the world have a more regular sequence of weather, due mainly to the change between winter and summer conditions. In the tropics there is no sequence of the seasons at all, only the difference between the drier months and the period of the rains. As will be seen in these maps, there are large areas which are mainly sunny, marked by the symbol of the sun, and large areas which are mainly rainy, marked by symbols of clouds; and their position on the globe changes according to the season. Canada and Russia in the far north have much sunshine in winter. This, and the fact that the air is relatively dry, makes the intense cold there more bearable.

The extreme frosts sometimes recorded in Britain are in no way as severe as those experienced in the coldest parts of the earth. In high latitudes the ground is frozen solid to a great depth, and the brief thaw in summer only melts the first few feet near the surface. In Canada, the Great Bear Lake on the Arctic circle is frozen 8 ft. thick in winter; and at Fort Good Hope on the Mackenzie River, a temperature of −79° F. has occurred. The coldest spot on earth is believed to be the Russian village of Verkhoyansk, east of the Lena River, and here a temperature of −94° F. was once recorded. Other low-level records are −66° F. at Yellowstone Park, U.S.A., and −76° F. near Ross Island in the Antarctic. The extreme temperature in winter at the south pole is not known.

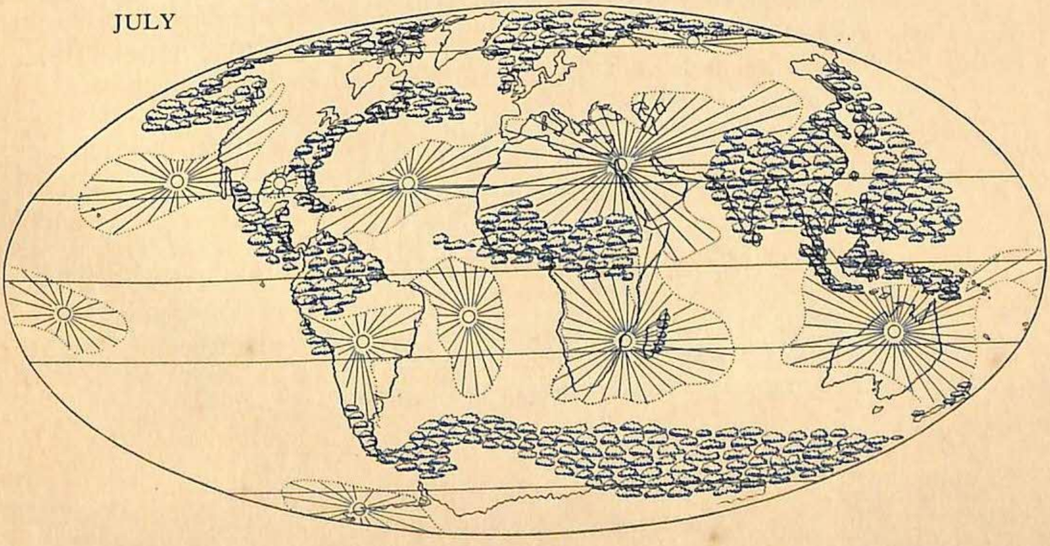
Excessive heat is easier to bear if the air is dry. When the air is very humid as well as hot, we are soon exhausted by any sort of activity. At

Belém, Brazil, the temperature does not usually much exceed 90° F., but the great and continuous humidity makes the heat hard to endure. For the same reason, places like Singapore, Malaya, or Madras, India, or Freetown, Sierra Leone, are unsuitable for white people to live in for more than quite short periods. In dry, desert regions, much higher temperatures occur. We complain if the temperature approaches 90° F. for a few days; but at Marble Bar, north-western Australia, a temperature exceeding 90° F. once occurred on over 150 days in succession. Even Sydney on the coast of Australia once touched 113·6° F., and frosts are rarely recorded there. In the Sahara desert, summer temperatures of over 120° F. are frequent. The record heat of any place on earth is 136° F. at Azizia in Tripoli, while Death Valley in California has recorded 134° F.; and Jacobabad in the desert of Sind, Pakistan, has recorded 130° F. At Jacobabad the mean rainfall is only 4 inches in a whole year.

JANUARY



JULY



Royal Meteorological Society

The Rainbow

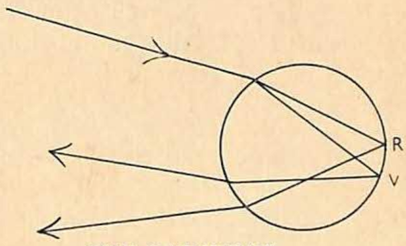
DID you know that a rainbow can be made? A good shower of water is needed, which may be devised by fixing a fine-spray nozzle to a hose-pipe so as to get a well spread out cloud of water drops. With our back to the sun, we observe the water from a distance of some feet. By moving the eye up or down or sideways, we soon find the right angle from which to see the rainbow. It will probably be whitish, or not strongly coloured, because for strong colour a cloud of large drops is needed, which is not easy to arrange. This experiment is best done on a lawn or other open space, when there is a low sun, and it is better with a dark background, such as trees.

Can we reach the end of the rainbow? This question is often asked, as if the end were a long way off. But it may be fairly close: we may see it coming down into the same field in which we stand, or between us and the wall of a house near at hand, or even in our own shower of water on the lawn. The truth is, it is only a matter of getting the right angle between our eye, the raindrops, and the sun. And to do this, we are obliged to stand at a distance of some feet, and so we cannot touch the raindrops at the same time. So if we see a rainbow, it is no good trying to walk nearer. This merely makes the rainbow appear to be moving farther on, which it is, for we are no longer seeing the same rainbow, but other water drops coming into view at the same angle.

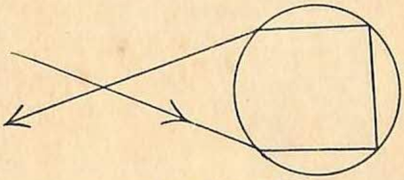
Rays of light that jump straight off a surface are said to be reflected; rays that are bent in passing through a substance such as water are said to be refracted. We see a reflection when we look in a mirror; refraction we observe when a stick is dipped in water and its lower part, from above the surface, appears bent. To understand why we only see the colours of a rainbow at a certain angle we must look at the single raindrop shown in the diagram. This is enlarged so that we can see clearly the course of a ray of light from the sun. As the ray enters the drop it is refracted, and as different colours are refracted different amounts, the red is reflected from the back of the raindrop at *R* and the violet at *V*. As these coloured rays emerge from the raindrop they are refracted still more and so are seen at different angles. Sunlight is composed of many colours, and it is in this way that the colours become separated for us to see. Sometimes there is a double reflection, as shown in the second diagram. This, for simplicity, only shows one coloured ray emerging. Of course we do not see single drops, but millions of them together, like a wall of falling water; and as we look towards the shower, the drops which happen to be at the required angle with the sun will form the rainbow.

How many colours are there in the rainbow? The principal colours actually observed are only five—red, yellow, green, blue, and violet. Usually they are brilliant bands of pure colour, though where they overlap there is sometimes an intermediate hue such as orange. We see the most brilliant colours when the falling rain is composed of large-sized drops, as in a thunder shower. When the drops are small the red is less brilliant, or may be altogether missing; sometimes other colours may be absent too. When the drops are very small, as in a fog, there are no colours, and the bow is white.

When well seen, the rainbow appears double. There is the principal or primary bow, and farther out, a little fainter and broader, the secondary bow which is formed by double reflection from the drops. The red is always on the outer edge of the primary bow; and in the secondary bow the colours are in the reverse order, with red on the inside. Along the inner edge of the primary are sometimes seen faint 'supernumerary' bows of purple, green, or pink; and the whole area of sky within the primary bow appears brighter than the rest of the sky. We have our back to the sun and the rainbow is centred on a point exactly opposite the sun. The primary bow is about 41° and the secondary 52° from this centre, these being degrees of arc as on a protractor. It therefore follows that the rainbow will appear larger if the sun is low: from an aeroplane it is possible to see a rainbow as a whole circle, but this cannot happen on the ground because the earth gets in the way.



THE RAINDROP



DOUBLE REFLECTION

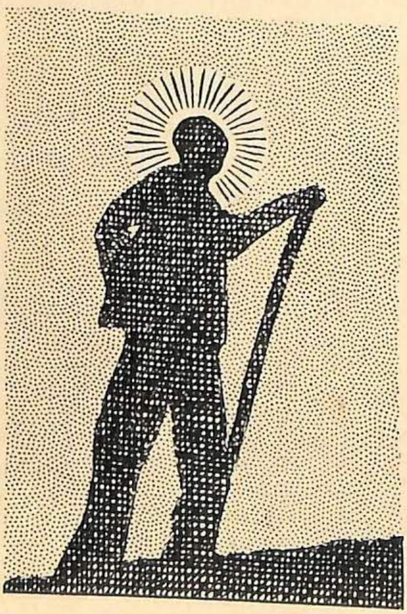
CORONAS

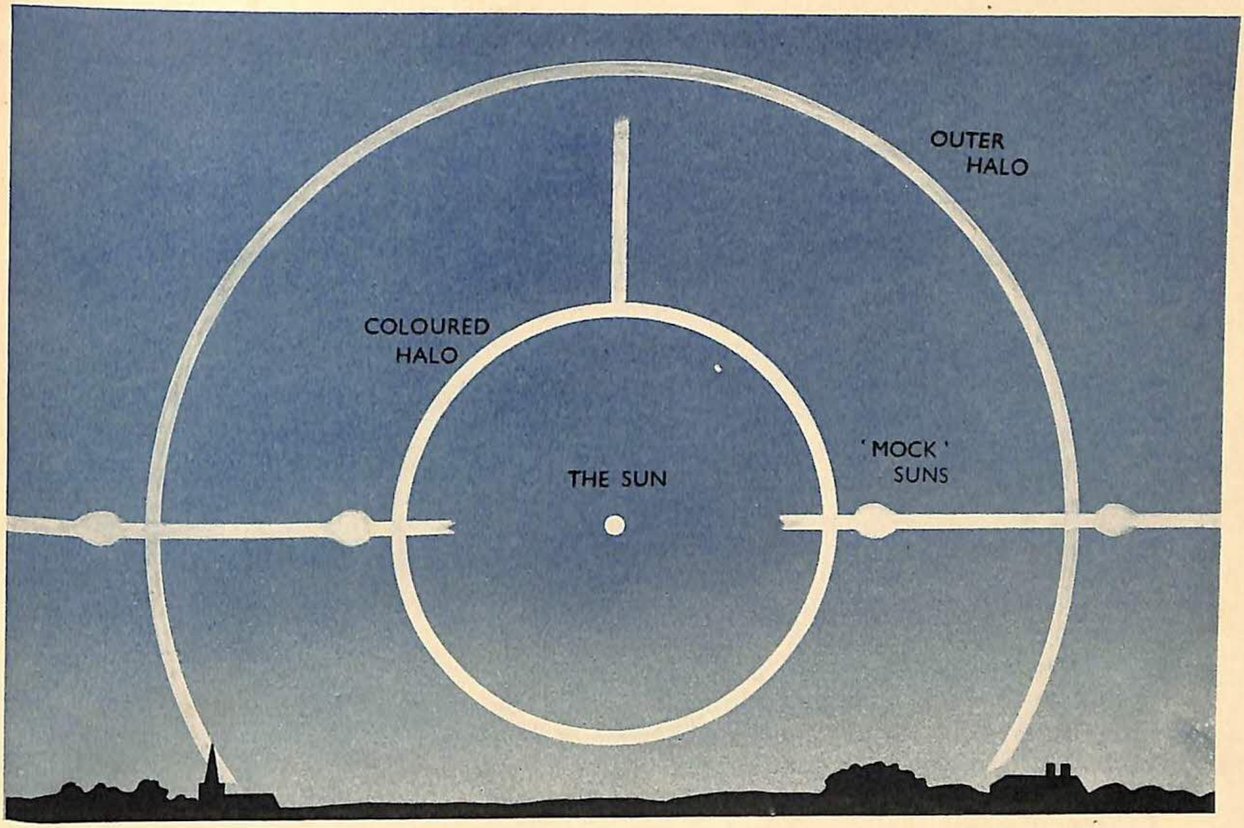
SOMETIMES we may see a small hazy ring of light around the sun or moon; this is called a corona, meaning a circlet or crown of coloured light. There may be a bluish tint on the inside, but the outer edge is always reddish or brownish; occasionally the colours may be repeated in two or more rings. There is nothing unusual about such coronas; they occur whenever the sun or moon shines through light clouds composed of minute water drops. The same sort of thing can be seen surrounding a bright electric-lamp bulb in a steamy bathroom.

STRANGE SIGHTS IN THE SKY

ANYONE climbing up a mountain side, or walking on the top of a high hill, may sometimes see a bank of low cloud or mist at a lower level. If the sun happens to be shining so as to cast a shadow of the climber on to the cloud, there will be no proper background to give scale, and so the human shadow will appear enormous. More curious still, in certain conditions of atmosphere, there may appear a Glory or coloured ring around the shadow of the head, so that the figure looks just like a saint. This Glory may only be seen around one's own shadow, and not around those of others seen at the same time. The pilot of an aeroplane may sometimes see the black silhouette or shadow of his aircraft far below him surrounded by a Glory in just the same way.

We have seen that the different varieties of cirrus cloud are all composed of ice crystals because the clouds form at a height where the temperature is well below freezing-point even on the hottest day. The ice crystals, though very minute, are like little hexagonal plates or hexagonal bars. Sometimes these will join together forming little miniature collar-studs. When the powerful sunshine is intercepted by a cloud of such crystals, the sun itself appears hazy, but the myriad crystals floating everywhere reflect the sunlight at certain angles, and refract the light in other directions, giving effects rather like a rainbow. Unlike the corona, which is seen close to the sun, a large coloured halo may be seen at some distance from the sun, and as a complete circle. The colours are usually rather faint, with the red on the inside of the circle. Sometimes a still larger outer halo may be seen, or we may only glimpse a part of it. The horizontal band of light runs parallel with the horizon, and on it are generally seen coloured patches called 'mock suns'. Other arcs and circles, besides those shown, may also be seen at times, and they may be quite spectacular, so that people think they have seen something extraordinary. The halo by itself, however, is fairly common, and has been seen in whole or in part on as many

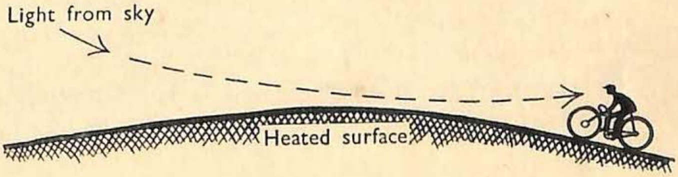




as two hundred days in the year. We often see reflection of the sun or moon on water. Sometimes a vertical ray or pillar of light is seen above the sun by reflection from cloud. When such a sun pillar, or even part of the outer halo, cuts across the horizontal band of light, people exclaim that they see a cross in the sky, which is true. And it may appear all the more vividly if it is seen by itself, without the other parts of the halo appearing.

MIRAGE

THE most striking example of a mirage is the apparent pool of water which raises the hopes of travellers in the desert. But we can see a mirage for ourselves on any hot day, above a heated tarmac road, if our eyes can be brought low, as they are when we cycle up a hill and see the heated surface in front of us. At first we see what appear to be rippling pools of water, but as our viewpoint changes they vanish in the hot air. A mirage is caused by the refraction of light from the sky in the heated air near the ground. Instead of striking the surface it is bent upwards so that we see the light above the surface instead of seeing the ground. Layers of warm air may likewise make distant objects appear elongated or doubled, and a ship at sea may appear raised above the horizon, or even upside down.



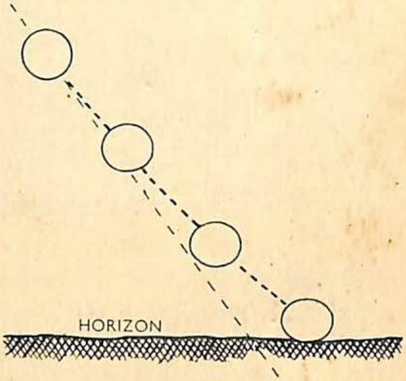
The Setting Sun

A SPLENDID sunset generally occurs when high clouds are present in great variety, and there are not too many low clouds to obstruct the view. The delicate and intricate beauty of such clouds is then not only better seen, but the clouds themselves are illuminated with gorgeous tints of yellow and pink and red. The sun's face is really white: it is only as it sinks towards the horizon that it appears orange. The rays of light have to travel through a great thickness of atmosphere; the blue gets scattered and gives us the blue sky and only the yellow and red rays reach us from the sun, so that it looks orange-coloured. When there is much dust or haze in the atmosphere the sun looks red, and the clouds also are tinted deep red.

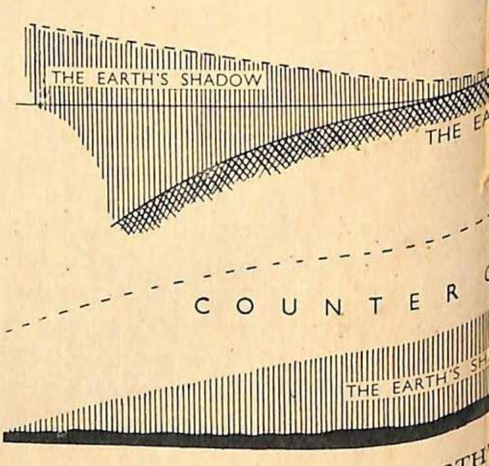
Another effect due to the great thickness of atmosphere through which the rays of light have to travel is the refraction or bending of the rays themselves. This refraction occurs with all celestial objects, and the nearer any object is to the horizon the more the rays become bent. The amount of this displacement on the horizon is about ½ degree, and it so happens that the disk of the sun is itself ½ degree in diameter. So when we see the lower edge of the sun touch the horizon, the sun is actually wholly below the horizon, as shown in the upper diagram. Since the amount of refraction increases towards the horizon, the lower edge of the sun is more refracted than the upper, and this gives the sun a squashed look as it sets. The diagram also shows how refraction causes the sun's path, as it approaches the horizon, to appear as a curve and not as a straight line.

Sometimes at sunset we may see the light move off the lower clouds and they darken, while the high clouds may still look pearly in sunlight. This is because the lower clouds are already in the earth's shadow, while for a time the higher clouds are still illuminated. If there were no atmosphere at all, the shadow side of hills, or even of buildings, would be completely black. As it is, scattered light from all directions in the atmosphere illuminates evenly everything not directly in sunlight.

CLOUDS AT SUNSET



REFRACTION GIVES THE SUN A SQ
ALSO MAKES THE SUN APPEAR ABOVE



THE EARTH'
SEEN RISING ABOVE THE EAST

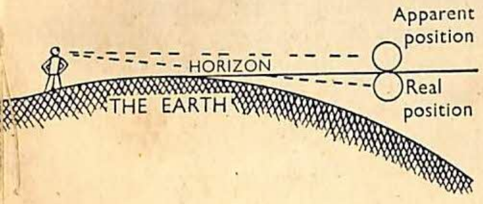
Fox Photos

A red sky at night is the shepherd's delight:
A red sky at morning is the shepherd's warning.

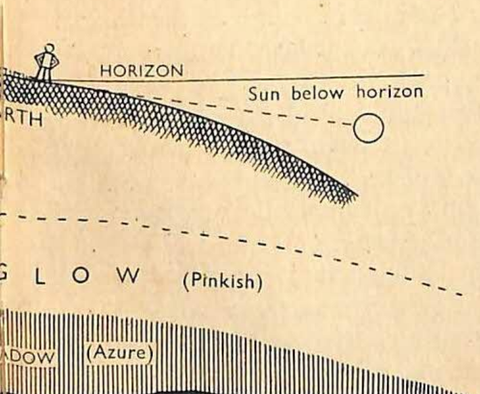
When the sun has gone down, the higher levels of the atmosphere still in sunshine diffuse light earthwards, and so we get a half light, which is called twilight; the darkness of night comes when the sun is far below the horizon.

People notice a fine sunset because the brilliant clouds attract attention; and when there are no clouds, they do not bother to look. Yet it is just when the sky is quite clear that we see the most wonderful effects. When the sun has set we see a golden yellow light all round the western horizon. It grades indefinably upwards to mingle with the darkening expanse of the heavens. Around the opposite or eastern half of the horizon is a much paler yellow light, often inclining to pink, called the counterglow. Here the particles of the atmosphere are reflecting the sunset colours just as clouds do. If we watch the eastern horizon the moment the sun has gone down in the west, we shall see, if the sky is really cloudless, a narrow band of darker azure blue between the counterglow and the true horizon. As the minutes pass, we see it rising as a huge arch, low above the eastern horizon: it is the shadow of the earth. Some ten minutes after sunset it may only extend three or four degrees above the horizon, and its edge is diffuse. But it is obvious by contrast with the slightly pink counterglow immediately above it. After twenty minutes or more the highest part of the arch may be 8 degrees above the horizon; but as it goes on rising, the edge becomes more diffuse, the pink above it vanishes, and the whole shape is lost in the darkening sky.

The word 'counterglow' is used in a different sense by astronomers, who give the name to a faint hazy patch in the heavens in a position almost opposite the sun after sunset. This is believed to be the earth's 'tail'. The haze is thought to be of hydrogen and other light gases that the earth trails away behind it as it travels through space. It is not possible to see this except in very favourable conditions; but the shadow of the earth may be seen whenever there are no clouds at sunset.

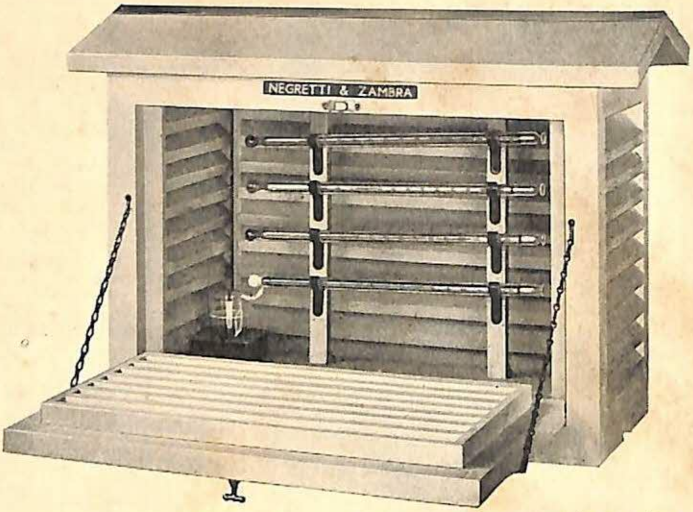


UASHED LOOK AS IT SETS, AND
THE HORIZON, THOUGH IT HAS SET



S SHADOW
ERN HORIZON AFTER SUNSET

RECORDING THE TEMPERATURE

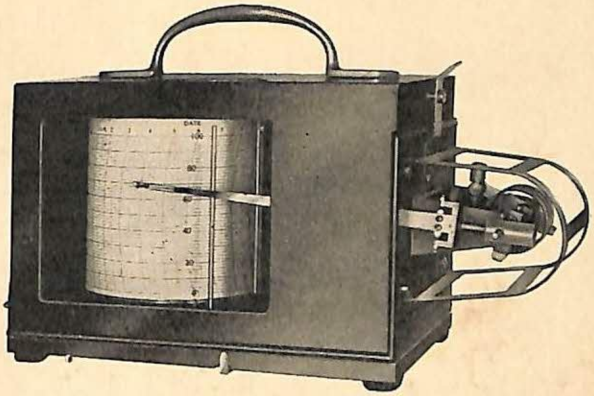


By courtesy, Negretti & Zambra

A 'MAXIMUM and minimum' thermometer of the kind already described, provided it is kept away from the direct rays of the sun, will tell us sufficiently accurately how hot or cold it is. At meteorological stations, however, the temperature must be recorded in a more exact manner, and so thermometers of proved accuracy are placed in a special way in order that readings from different stations may be strictly comparable. Since the thermometers have to be protected from the direct rays of the sun, they are placed in a cage called a 'screen'. This has its base 3 ft. 6 in. above the ground; it is painted white and looks rather like a bee-hive, but has open louvred sides so that the air can circulate freely. The picture shows a small screen which contains four thermometers. Readings of these are taken at least once a day at a fixed hour.

The upper thermometer in the screen indicates the maximum temperature, and is re-set by shaking it, just like a medical thermometer. The second one is a spirit thermometer with a sliding index which is carried along with the spirit as the temperature falls; but as the temperature rises, the spirit flows past it, and so the index shows the minimum temperature that has occurred. The thermometer is re-set by tilting it until the index slides back to the end of the column of spirit. When a temperature below freezing is indicated, it will also be below freezing on the ground level; but sometimes a slight frost may occur on the ground which the thermometers in the screen cannot indicate. So another minimum thermometer is sometimes placed on short grass in such a way that it just touches the tips of the grass. Growing plants are not hurt by frost until the temperature falls some way below freezing-point. So 'ground frost' is not officially recorded until the temperature has fallen to 30° F. (or 30·4° F. if read to tenths of a degree).

Special thermometers are also used for measuring the temperature at different depths in the earth, or in the sea. The most interesting thermometer is called a Thermograph. Outwardly this looks like the Barograph already described, but it is worked by a coiled spring made of different metals which expand and contract with the changing temperature. A lever works a pen on a drum, giving a continuous record of the temperature day and night. A similar metal coil is used in instruments which record the temperature on a dial.



By courtesy, Negretti & Zambra

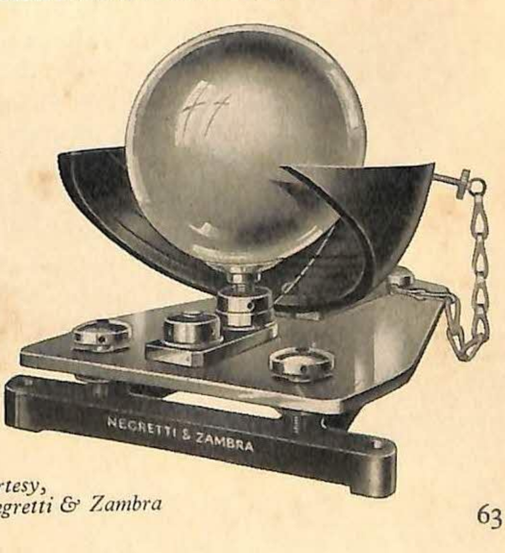
THE THERMOGRAPH RECORDS THE TEMPERATURE

The relative humidity of the air is determined by taking readings of the lower pair of thermometers in the screen, which are called the 'dry' and 'wet-bulb' thermometers. The 'dry' is merely an ordinary one, but the 'wet-bulb' thermometer has its bulb covered with muslin kept wet by a wick trailing into a small bottle of water. We all know that, when we come out of the water after a bathe, we feel even colder than when we were in the water. This is because the water on us is evaporating, and in doing so it chills us. The thermometer that is kept wet is chilled too, because the water on the muslin is evaporating; so it reads, generally, a few degrees lower than the dry thermometer. The difference between the two readings gives us, by reference to printed tables, the relative humidity of the air. If the air is so humid as to be at saturation or dew-point, no water will evaporate from the wet muslin, and the two readings will be alike. On a hot, dry day evaporation will be rapid and there will be a large difference between the readings. Difference in humidity is very noticeable on a washing day. Clothes will not dry if the air is very humid: but even woollens dry quickly if the air is dry and warm.

A handy but rather less accurate way of determining humidity depends on the fact that a human hair has the property of reacting strongly to the amount of moisture in the air. The expansion and contraction of a hank of hair is therefore made to work a pointer on a dial, which shows at a glance what the humidity is.

THE SUNSHINE RECORDER

THIS is an instrument which records the total number of hours of sunshine each day. It consists of a 4-inch diameter glass sphere which acts as a lens or burning-glass. A strip of specially prepared card is inserted each day into a curved metal bowl beneath the sphere, and whenever the sun shines clearly the glass forms an image of the sun which, as it travels along, burns a line on the card. If the sun shines intermittently, there will be several broken lines, and their length is added together to get the total sunshine for the day. The instrument must be correctly fixed for the appropriate latitude, but once set needs no further adjustment. Cards of three different shapes have to be used for the summer, winter, and spring or autumn; they are clamped in position by a small screw on the end of a chain.



By courtesy, Negretti & Zambra

BOOKS FOR FURTHER READING

HAVING seen for yourself some of the interesting things that occur in the atmosphere you may wish to read more about them. *The Drama of Weather*, by Sir Napier Shaw (Cambridge University Press), contains many photographs and pictorial diagrams. *Weather*, by G. Kimble (Pelican Series, Penguin Books), is a comprehensive account, and includes weather lore. For details of different aspects of the subject you may also consult, under the appropriate headings, vol. III of the *Oxford Junior Encyclopaedia* (Oxford University Press). All the sayings about the weather will be found in *Weather Lore*, by Richard Inwards, with scientific notes by E. L. Hawke (Royal Meteorological Society, or Rider & Co.).

Of the many good introductory books, *Weather*, by W. G. Kendrew (Oxford University Press), contains all the essential facts, and is small enough to go into the pocket; and there is also *A Short Course in Elementary Meteorology*, by W. H. Pick (H.M. Stationery Office). Advanced text-books of meteorology require a good knowledge of mathematics and physics; but some standard works which are largely descriptive may be mentioned for the special information they contain. *The Climate of the Continents*, by W. G. Kendrew (Oxford University Press) gives a vivid and complete account of the climates in the main geographical regions of the world. *The Climate of the British Isles*, by E. G. Bilham (Macmillan & Co.) is mainly factual and useful for reference. *The Meteorological Glossary* (H.M. Stationery Office) is a thin volume packed with information, like an illustrated encyclopaedia. *Climate through the Ages*, by C. E. P. Brooks (Ernest Benn Ltd.), describes the changes in climate during the historical period, during the Ice Ages, and in the earlier geological epochs. A clear descriptive account of all that is now known about thunderstorms and lightning will be found in *The Flight of Thunderbolts* by B. F. J. Schonland (Oxford University Press).

Clouds are of interest to everybody, and C. J. P. Cave's *Clouds and Weather Phenomena* (Cambridge University Press) is a little book with many beautiful photographs and a brief, informative text. An illustrated booklet, *Cloud Forms* (H.M. Stationery Office), gives photographs showing the complete official classification. *Cloud Reading for Pilots*, by A. C. Douglas (John Murray, London), contains over 200 pictures, many of which are in sequence showing cloud formation.

The Daily Weather Report may be obtained by subscription for any period, with special rates per term for schools, from The Director, Meteorological Office, Air Ministry, Kingsway, London, W.C. 2. *The Weather Map* (H.M. Stationery Office) describes the subject in full. The monthly illustrated magazine, *Weather* (Royal Meteorological Society), contains popular informative articles on all subjects relating to the atmosphere.